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STOPPING
WATER POLLUTION
AT ITS SOURCE

MISA

Municipal Industrial Strategy for Abatement

TORONTO MAIN STP

MISA PILOT SITE STUDY

COMPONENT REPORT

WATER QUALITY

Environment
Ontario

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TORONTO MAIN STP PILOT SITE STUDY
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TORONTO MAIN STP MISA PILOT SITE STUDY
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EXECUTIVE SUMMARY

As a component of the Ministry's "Municipal-Industrial Strategy for Abatement" (MISA) program, the Ministry has evaluated several water quality assessment techniques at six "Pilot Sites" in Ontario. The site-specific water quality-based effluent limits consider the environmental sensitivity of receiving water bodies, and evaluate the potential need for effluent limits which are more stringent than those being developed by the technology track investigations.

The purpose of this report is to present and discuss the results of water quality surveys conducted in 1986 and 1987 in support of the Toronto Main STP MISA pilot site study. Several model predictions of effluent reductions required to achieve Provincial Water Quality Objectives (PWQO) for parameters of concern are compared. It should be noted that this report is a technical report that is not intended to set final policy.

<u>Findings</u>:

Dilution factors for various chemicals calculated for surface samples in the vicinity of the Main STP outfall are given in Table 1. The average initial dilution at the outfall station (1419) is approximately 1:3 for conservative parameters and 1:4 to 1:7 for parameters subject to decay. Within 1 km to the south of the outfall, the dilution is approximately 1:20 to 1:50. Exceedences of PWQO in the vicinity of the Main STP outfall are summarized in Table 2.

In the immediate vicinity of the outfall, only the ammonia and residual chlorine concentrations approach levels which are acutely toxic to the biota. For ammonia, the threshold for acute toxicity depends on both temperature and pH, but is approximately 10 mg/L total ammonia, for the temperature and pH observed during the study (Emerson, et

al., 1975). The average outfall concentration is 7.0 mg/L, and the PWQO is exceeded 75% of the time. A slight pH depression at the outfall slightly favours ionization of ammonia, thereby suppressing toxicity to some extent.

For chlorine, the acute toxic threshold for freshwater fish is approximately 50 to 200 μg/L (U.S. EPA, 1984). The average outfall concentration over the period of STP chlorination (June through September) is 330 μg/L, and the Provincial Water Quality Objective (PWQO) (2 μg/L) is exceeded 70% of the time. Based on observed water quality data, acute toxic effects would not be expected beyond a 500 m radius of the outfall.

Total phosphorus concentrations, average 0.2 mg/L near the outfall, almost always exceeding the provincial water quality guideline (0.02 mg/L), and are still above the background level of 0.015 mg/L at a distance of 3 km south of the outfall. These levels are of concern primarily because of potential stimulation of nuisance algal growth.

Iron, copper and cadmium exceed their provincial receiving water objectives at the outfall 77, 38 and 31% of the time, respectively. The average concentration of iron (0.456 mg/L) exceeds the provincial objective of 0.3 mg/L. Other heavy metals do not exceed objectives on average. Provincial water quality objectives are designed to provide protection to aquatic life from chronic toxicity. Acute toxic levels are not approached by any heavy metal.

Fecal coliform bacteria, suspended solids and conductivity are of interest primarily as surrogates for human pathogens or toxic contaminants that may be either adsorbed to particulates or dissolved. All these parameters approach background levels within 1 km of the outfall, but are two to three times higher than background at the outfall.

The organochlorine pesticides lindane and heptachlor have exceeded provincial water quality objectives at the outfall. Only lindane is frequently in exceedence (17% of the time in 1986, 46% in 1987). However, even at the maximum concentrations observed, structure-activity models suggest that chronic toxic effects from these chemicals on aquatic biota are almost certainly absent. Average lindane concentrations at the outfall (10 μg/L in 1987) are equal to the provincial water quality objective, and are an order of magnitude

below the chronic toxicity threshold.

Ultra-trace methods (16-L effluent and 200-L lake water samples) were used to measure the concentrations of PCBs, organochlorine pesticides and chlorobenzenes in the STP effluent and receiving water. Within the lake, few contaminants are present at concentrations above 1 ng/L. Such contaminants include the dichlorobenzenes, α-BHC, γ-BHC (lindane) and, in October 1987, total PCBs in 23 of 30 samples collected. This finding is most significant for total PCBs for which the PWQO is 1 ng/L. Several other chlorinated benzenes were present at concentrations between 0.1 and 1 ng/L. Other contaminants averaged below 0.1 ng/L.

In the STP effluent, the various chlorinated benzenes and PCBs were always found using ultra-trace methods. Mean loadings for these compounds were as high as 630 g/day (1,4-dichlorobenzene); the mean loadings for total PCBs and lindane were 17 and 21 g/day, respectively. Average effluent concentrations of these three compounds were 710, 20 and 24 ng/L, respectively. However, these loadings are minor compared with those from external sources, in particular the atmosphere and Niagara River. In addition to loading reductions from Toronto sources, PCB loadings from other sources discharging to Lake Ontario must be reduced considerably in order to achieve compliance in the Toronto Waterfront.

The size and direction of the effluent plume may easily be established by tracking using parameters which are easily measured on board the survey vessel, such as conductivity, ammonia and chlorine residual. The magnitude of the effluent plume is strongly influenced by the lake currents. Weak currents (<5 cm/s) result in rapid dilution within several hundred metres of the outfall. On the other hand, strong currents (> 15 cm/s) produce poor dilution, and the effects of the plume can be observed for as much as 6 km from the outfall, even in the vicinity of the R.C. Harris WTP intake. However, as the plume is at the surface, increased concentrations are unlikely to be found at the depth of the WTP intake.

Historical data suggest that conductivity, turbidity and total ammonia have been generally decreasing on the Toronto Waterfront in the recent past; however, the Don River mouth

and Main STP outfall have shown opposite trends since 1983. Total phosphorus has been generally increasing on the Toronto Waterfront, especially in the vicinity of the Don River mouth and Main STP. Thus, these two sources are further implicated by long-term temporal trends as major influences on local water quality.

Total ammonia in the Main STP effluent shows a consistent pattern of increase over the course of the day from about 10:00 a.m. to 5:00 p.m. Phosphorus is more tightly controlled, though extremes tend to occur late in the day. Flow may either increase or decrease over the course of the day. Both ammonia and flow exhibit large day-to-day variations.

Long-term prediction of daily average effluent outfall concentrations may be possible with some success based on daily average concentrations in the Main STP effluent. However, short-term prediction based on instantaneous effluent measurements requires a hydrodynamic model which explicitly accounts for receiving water conditions. Existing data are inadequate for development of these predictive relationships.

Derivation of Effluent Limits

For parameters of concern, the allowable load is the load for which the defined objective (in most cases the PWQO) will be satisfied for a specific fraction of the time at the edge of any defined mixing zone. For the purpose of this exercise, two scenarios were modelled: a mixing zone of 500 m radius about the outfall, and no mixing zone (i.e. zero radius - achieve PWQO at the edge of near-field diffuser mixing). Also for the purposes of this exercise, the water quality-based effluent limits were derived on the basis of 95% compliance with objectives - i.e. no parameter will be allowed to be out of compliance more than 5% of the time, given the statistical variability of contaminant loadings. Parameters of concern include those which frequently exceed objectives near the outfall.

Initial dilution factors above the outfall (i.e. station 1419 - edge of near-field mixing) have been defined from average water quality data (Table 1). Using only average to worst-case current conditions, the mean far-field dilution rate was found from plume-tracking experiments to be 9%/100 m for conductivity and ammonia, and 19%/100m for chlorine residual. The higher rate for chlorine residual reflects its rapid chemical and biochemical

decay. These rates were combined with loading data to estimate the extent of reduction required in order to meet the stated objectives or guidelines at zero or 500 m radius from the outfall (Tables 3, 4).

In addition, two models were used to predict allowable loadings at the present and proposed outfall sites. The dilution model combines the effects of diffuser geometry, water depth and mixing depth to estimate initial dilution, plus receiving water hydrodynamics to estimate far-field dilution. The fate model uses modelled lake hydrodynamics for the Toronto Waterfront nearshore area plus processes such as volatilization, sorption, bio-uptake and sedimentation to estimate in-lake concentrations at various distances from the outfall, from assumed loading values. However, it suffers from the limitation that concentrations are calculated on the basis of 500 m grid squares; thus the "zero" mixing zone result is actually an average of up to 250 m from the outfall. Similarly for the 500 m mixing zone, it represents an average of 250-750 m. In addition, modelled hydrodynamics used in the fate model near the edge of the modelled area (i.e. proposed outfall) are known to be less accurate. For these reasons, only the dilution model results are presented in this summary with the plume track results.

The dilution model was run for average conditions at the existing outfall location, plus a proposed outfall with a 1000 m diffuser located about 3.7 km from shore in a water depth of at least 15 m. Results of this model are also summarized in Tables 3 and 4.

For a zero mixing zone at the existing location (Table 3), required loading reductions range from 50-70% (iron, lindane) to 96-98% for total phosphorus and greater than 99% for chlorine residual. At 500 m mixing zone radius (Table 4), the required reductions are only slightly lower for most parameters due to slow far-field dilution which occurs under most current conditions. However, if the proposed outfall is adopted, objectives should be met for all parameters except total phosphorus, chlorine residual and (for zero mixing zone) ammonia. This is due to the improved diffuser design as well as greater initial dilution resulting from the improved water depth.

It must be kept in mind that these loading reductions are estimates which are subject to inherent variability due to short-term changes in loadings or receiving water physical

conditions which are hard to define. However, they represent a range from average to worst-case conditions in order to provide realistic estimates of required dilutions for conditions which prevail at both the existing and proposed locations for the largest part of the time.

Conclusions and Recommendations:

The extent of loading reductions required to meet Provincial Water Quality Objectives at various locations, has been estimated using the plume tracking results and dilution model explained above. It should be noted that these are only estimates of required reductions; the final model for loading reduction calculations has not been selected, nor has the allowable distance from the outfall been finalized.

The main conclusions and recommendations of this study are as follows:

1. It is important that site-specific water quality-based effluent limits be developed for individual dischargers. This is evident due to the difference in effluent reductions required for the present and proposed outfalls.

2. Dechlorination of the final effluent will be necessary in order to meet Provincial Water Quality Objectives (PWQO) in the receiving water.

    - At the existing outfall location, in order to meet PWQO at the end of the pipe 95% of the time, residual chlorine levels in the final effluent must be reduced by 99.6% to 5 μg/L. In order to meet PWQO at the edge of a 500m mixing zone 95% of the time, final effluent chlorine levels must be reduced by 99% to 16 μg/L.

    - At the proposed offshore outfall location, in order to meet PWQO at the end of the pipe 95% of the time, chlorine levels in the effluent must be reduced by 97% to 47 μg/L. In order to meet PWQO at the edge of a 500m mixing zone 95% of the time, chlorine levels in the effluent must be reduced by 94% to 86 μg/L.

3. Ammonia removal in the final effluent will be necessary to meet PWQO in the receiving water under summer conditions.

- At the existing outfall, in order to meet PWQO at the end of the pipe 95% of the time, ammonia levels in the final effluent must be reduced by 88-93% to 2.3-4.3 mg/L. Similarly, for the edge of a 500m mixing zone, the levels must be reduced by 79-87% to 4.3-6.9 mg/L.

- At the proposed offshore location, in order to meet PWQO at the end of the pipe 95% of the time, ammonia levels in the final effluent must be reduced by 28% to 23.5 mg/L. However, no reduction in effluent ammonia levels is required to meet PWQO 95% of the time at the edge of a 500m mixing zone.

4. Enhanced phosphorus removal (tertiary treatment) of the final effluent will be necessary to meet the Provincial Water Quality Guidelines (PWQG) for prevention of nuisance algal growth.

- At the existing outfall location, in order to meet the PWQG at the end of the pipe 95% of the time, final effluent total phosphorus levels must be reduced by 96-98% to 24-46 μg/L. Similarly for the edge of a 500m mixing zone, the level must be reduced by 95% to 68 μg/L. Based on dilution model predictions, distances of 17 and 35 km are required for dilution to PWQG of effluent concentrations of 0.5 and 1.0 mg/L, respectively.

- At the proposed offshore outfall location, in order to meet PWQG 95% of the time at the end of the pipe, final effluent total phosphorus levels must be reduced by 80% to 245 μg/L. Similarly for a 500m mixing zone, the levels must be reduced by 65% to 440 μg/L. Based on dilution model predictions, distances of 0.7 and 3.6 km are required for dilution to PWQG of effluent concentrations of 0.5 and 1.0 mg/L, respectively.

5. At the existing outfall location, loading reductions of heavy metals and organic contaminants will be necessary in order to meet PWQO in the receiving water. However, improved dilution characteristics at the proposed offshore outfall location will allow PWQO for these parameters to be achieved after initial dilution.

- In order to meet PWQO for copper at the end of the pipe 95% of the time at the existing outfall location, the final effluent level must be reduced by 65-75% to 10-15 μg/L. Similarly, for the edge of a 500m mixing zone, the required reduction is 43-58% to 18-24 μg/L. Required reductions for other metals and organics such as lindane are lower and should be achieved if the above reductions are met.

- In the case of PCBs, loading reductions of 93 to 95% are estimated for zero and 500 m mixing zones, based on average observed background levels. However, the highest background PCB levels are similar to the PWQO of 1 ng/L; hence required loading reductions may be as high as 100% for either outfall location.

Recommendations for Further Study

A number of recommendations for design of future pilot studies were suggested. In general, the study design should be derived from the study objectives. When there are multiple study objectives, each sampling activity should be related to one of these objectives so that sampling design can be optimized.

While short-term (i.e. daily cycle) studies may be valuable for modelling purposes, study objectives should address the long-term question of objective compliance. For these purposes, daily 24-hour composite sampling, supported by more frequent (hourly to 3-h) grab sampling, should be conducted for one or two weeks per survey. Based on the results of the short-term survey, effort should be made to limit temporal sampling bias, both between days and between regions. For these purposes, a specific sampling design should be adopted, including a series of fixed stations and depths.

In addition, further refinement of mixing zone models for adequate description of near-field dilution (initial mixing) is required. Such refined models could be used to run conditions of existing treatment at the new outfall location to determine the size of mixing zone required for various parameters of concern, such as total phosphorus and ammonia.

When large amounts of "below detection" data are obtained, careful consideration to handling such data is required. Statistical methods such as the maximum likelihood method provide the best estimate of overall conditions; however, the best solution to this problem is improved detection limits in the laboratory for critical substances such as PCBs.

TABLE 1: DILUTION FACTORS[1] FOR DIFFERENT CHEMICALS AT SELECTED INDIVIDUAL STATIONS IN 1987

Chemical Parameter[2]	Station Number[4]					
	1419	2877	2909	2878	2910	2209
Field Ammonia:						
0.5 m depth	3.1	32.	32.	14.	45.	80.
6.0 m depth	80.	300.	300.	45.	300.	-
Lab Ammonia	2.9	40.	110.	8.7	19.	110.
Residual Chlorine[3]	3.0	21.	28.	-	-	400.
Phosphorus	5.0	25.	40.	27.	40.	80.
Conductivity	3.0	18.	22.	14.	40.	100.
DOC	3.3	20.	27.	16.	50.	130.
Fecal Coliforms	6.6	470.	700.	27.	50.	700.
Copper	5.4	36.	100.	29.	29.	150.
Zinc	7.1	55.	150.	75.	70.	400.
Iron	4.1	20.	28.	16.	40.	30.
Manganese	3.2	17.	28.	12.	24.	75.

[1] Dilution Factor = (Source-Background)/(Concentration-Background)

[2] Chemical measured at 0.5 m water depth in receiving water, unless otherwise indicated.

[3] Source concentration of free chlorine assumed = 1000 μg/L; other concentrations averaged over period of Main STP chlorination (June-September).

[4] Station locations are shown on Figure 1.2.

TABLE 2: EXCEEDENCE OF CONVENTIONAL AND METAL WATER QUALITY OBJECTIVES AT STATION 1419 OVER THE MAIN STP OUTFALL

(see Appendix 2 for complete statistical summary)

	1986		1987		
Parameter	N	%	N	%	PWQO[1]
0.5 m Depth					
Residual Chlorine***	7	100	13	70	2.0 µg/L
Field Ammonia	6	100	12	75	0.02*
Lab Ammonia	6	100	-	-	0.02*
Phosphorus	10	100	14	100	0.02
Iron	10	40	13	77	0.30
Copper	10	30	13	38	0.005
Cadmium	10	20	13	31	0.2 µg/L
Lead	-	-	13	0	0.025**
Nickel	10	0	13	0	0.025
Mercury	9	11	13	8	0.2 µg/L
6 m Depth					
Residual Chlorine***	6	100	5	0	2.0 µg/L
Field Ammonia	6	67	8	0	0.02*
Lab Ammonia	6	50	-	-	0.02*
Phosphorus	10	80	4	100	0.02
Iron	9	22	4	25	0.30
Copper	9	11	4	25	0.005
Cadmium	9	11	4	25	0.2 µg/L
Lead	-	-	4	0	0.025**
Nickel	9	0	4	25	0.025
Mercury	8	0	4	0	0.2 µg/L

Note: N = Number of samples taken.

[1] PWQO in mg/L unless otherwise indicated; phosphorus value is a guideline only.

* Ammonia objective is for unionized fraction.

** Lead objective is alkalinity-dependent; alkalinity = 80 mg/L was assumed.

*** Chlorination period (to end of September) only.

Table 3: **Summary of load allocations (Kg/d) for 95% PWQO compliance target, based on zero mixing zone calculated by different methods**

	Observed	Existing Outfall						Proposed Outfall		
	1987	Dilution Model			Plume Track			Dilution Model		
Parameter	95%ile load (kg/d)	Outfall concn µg/L	Allowable load Kg/d	% redn req'd	Outfall concn µg/L	Allowable load Kg/d	% redn req'd	Outfall concn µg/L	Allowable load Kg/d	% redn req'd
Ammonia	$3.2x10^4$	2.3 mg/L	2200	93	4.3 mg/L	$4.1x10^3$	88	23.5 mg/L	$2.3x10^4$	28
Chlorine res.	$1.4x10^3$	4.6	4.4	99.7	5.6	5.4	99.6	47	45	97
Total Phosphorus	$1.2x10^3$	24	23	98	46	44	96	245	235	80
Iron	$2.0x10^3$	660	630	69	1030	990	51	6600	6300	0
Copper	40	10	10	75	15	14	65	95	91	0
Cadmium	3.3*	0.46	0.44	87	0.7	0.7	79	4.7	4.5	0
Lindane	65**	22	21	68	33	32	51	210	200	0
PCB	40**	1.5	1.4	97	2.0	1.9	95	10	10	75

Note: Dilution model figures are from table 4.2
Plume track figures are from table 4.5

* 1986 data
** Lindane and PCB loadings are in g/d; concentrations in ng/L

Table 4: *Summary of load allocations (Kg/d) for 95% PWQO compliance target, based on 500 m radius mixing zone calculated by different methods*

Parameter	Observed 1987 95%ile load (kg/d)	Existing Outfall – Dilution Model: Outfall concn µg/L	Existing Outfall – Dilution Model: Allowable load Kg/d	Existing Outfall – Dilution Model: % redn req'd	Existing Outfall – Plume Track: Outfall concn µg/L	Existing Outfall – Plume Track: Allowable load Kg/d	Existing Outfall – Plume Track: % redn req'd	Proposed Outfall – Dilution Model: Outfall concn µg/L	Proposed Outfall – Dilution Model: Allowable load Kg/d	Proposed Outfall – Dilution Model: % redn req'd
Ammonia	$3.2x10^4$	4.3 mg/L	$4.1x10^3$	87	6.9 mg/L	$6.6X10^3$	79	43 mg/L	$4.1x10^4$	0
Chlorine res.	$1.4 x10^3$	8.6	8.3	99.4	16	15	98.9	86	83	94
Total Phosphorus	$1.2x10^3$	53	51	96	68	65	95	440	420	65
Iron	$2.0x10^3$	1220	$1.16x10^3$	42	1630	$1.56x10^3$	22	12000	$1.2x10^4$	0
Copper	40	18	17	58	24	23	43	172	165	0
Cadmium	3.3*	0.86	0.83	75	1.2	1.1	67	8.6	8.3	0
Lindane	65**	40	38	42	53	51	22	390	370	0
PCB	40**	2.3	2.2	95	2.9	2.8	93	18	17	58

Note: *Dilution model figures are from table 4.2*
Plume track figures are from table 4.5

* *1986 data*
** *Lindane and PCB loadings are in g/d; concentrations in ng/L*

1.0 INTRODUCTION

Under the Municipal and Industrial Strategy for Abatement (MISA) being developed by Ontario, all dischargers in the province will be required to update their pollution control technology at least to the level of BATEA (Best Available Technology Economically Achievable). If receiving water quality conditions so dictate, the dischargers may be required to achieve even higher levels of pollution control. Regulations to govern the allowable discharge from various industrial and municipal sectors are being developed by MOE based on BATEA; intensive studies are being conducted at six "pilot sites" situated in various parts of the province to examine effluent requirements based on receiving water conditions. The Toronto Main Sewage Treatment Plant (STP) was selected as a pilot site, as it is one of the largest municipal sewage treatment plants discharging to the Great Lakes and receives influents from a large variety of sources (i.e., industrial, domestic, storm overflow).

Given that protection of the environment is the ultimate goal of the MISA initiative, the MOE additionally undertook to examine site-specific, water-quality-based effluent limits at the six pilot sites, to protect environmentally sensitive areas, to develop assessment protocols and to eventually assess those effluent requirements relative to those prescribed by BATEA. Water quality based effluent limits can be derived through the use of sophisticated modelling techniques which establish a predictive link between effluent quality and specific effects on the aquatic environment. Additionally, the results of the Main STP study are expected to contribute significantly to the development of the Toronto Waterfront Remedial Action Plan (RAP). The RAP is being prepared for the International Joint Commission (IJC) by a combined federal-provincial work team, in cooperation with the municipalities and a formal public advisory committee, and will consider all possible measures of ecosystem quality restoration for the Metro Toronto Waterfront.

This report presents the results of the Main STP Pilot Study for 1986 and 1987, in relation to historical data (back to 1976), and in relation to concurrent data for the entire Toronto

Waterfront (Etobicoke Creek to Rouge River). Sampling and chemical analysis were performed by the Ontario Ministry of the Environment (MOE). A portion of the data analysis and evaluation as described here was performed by Beak Consultants Ltd. under contract to MOE.

1.1 Study Objectives

In order to develop standard procedures for the derivation of receiving-water-based effluent limits, the MOE has evaluated numerous traditional and novel water quality assessment techniques. These techniques have been applied on a site-specific basis at the Toronto Main STP pilot site, as well as at the other Pilot Sites throughout Ontario, to determine their suitability in establishing water quality-based effluent limits.

Two distinct goals were expressed at the outset of these Pilot Site investigations, which were initiated in 1986. These goals are:

- To develop site-specific effluent requirements for hazardous and conventional pollutants from specific dischargers, based on receiving-water impact assessment.

- To develop and document, for application to other comparable discharger and receiving-water situations in the province, an acceptable set of receiving-water assessment techniques and procedures.

As a basis for determining the impacts of toxic contaminants on the aquatic environment, the Toronto Main STP study team has relied on Provincial Water Quality Objectives (PWQO's) and Guidelines (PWQGs), and advisories as well as water- and biologically-based criteria, developed by other government agencies to determine acceptable conditions.

Specifically to the Main STP pilot site, the objectives have also included determination of the relationship between in-lake contaminant concentrations and causative factors such as

local effluent inputs, wet weather inputs, advection, dispersion, external sources and sedimentation; and the estimation of the impact of input reductions on the zones of non-compliance with PWQOs and PWQGs in the vicinity of the Main STP.

1.2 Site Description and Inputs

The Toronto Main STP is located on the east side of the Metro Toronto Waterfront, which stretches from Etobicoke Creek at the western limit of Metro Toronto to the Rouge River at the eastern limit of Metro Toronto (Figure 1.1). With a design flow of $8.18 \times 10^5 m^3/d$ (180 MGD), the Main STP is the largest single municipal discharge, not only to all of Metro Toronto, but to the entire Lake Ontario shoreline.

The 45 km Metro Toronto Waterfront shoreline provides many attractions to the 2.1 million population of Metro Toronto as well as a large tourist population. Public attractions include Exhibition Park, Ontario Place, Centre Island and Harbourfront, as well as many swimming beaches and protected mooring for over 7,000 small craft (RAP, 1988). The watershed that drains to the lake includes the drainage basins of Etobicoke Creek, Mimico Creek, the Humber and Don Rivers, Highland Creek and the Rouge River. These are separated into western and eastern sectors by the Port of Toronto which encompasses the Don River, Ontario Place, the inner and outer harbours, the Toronto Islands and the Eastern Headland. Information on the geology, soils and land use of these watersheds is contained elsewhere (RAP, 1988); in brief, the lower reaches of all these watersheds are highly urbanized, while some agricultural area is still found in the upper (northernmost) areas.

Much of the western and eastern portions of the Lake Ontario shoreline in Metropolitan Toronto is relatively inaccessible to the public due to extensive private ownership, as well as rapid drops to the water's edge (especially at the Scarborough Bluffs). Two lakefill projects in the west (Colonel Sam Smith Park and Humber Bay Park), and one in the east (Bluffers Park) have provided increased public access to these parts of the waterfront. East of the Humber River are found recreational areas such as the Western Beaches as well as sailing and rowing clubs and marinas.

Toronto Waterfront

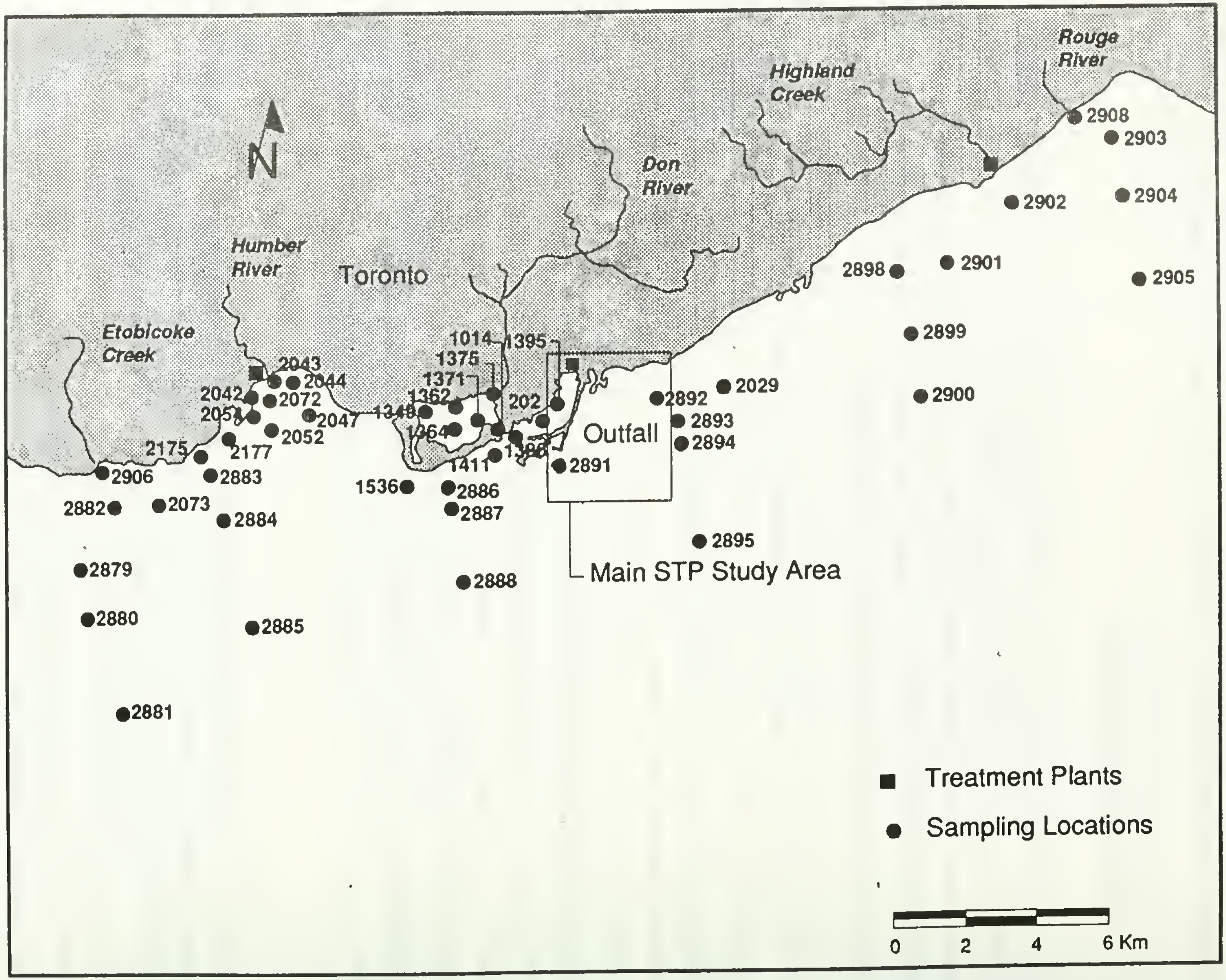


FIGURE 1.1 Location of Sampling Stations and Key Point Sources

The Central Waterfront is dominated by Toronto Inner and Outer Harbours, which are enclosed by natural and man-made features. While the Toronto Islands, which enclose the Inner Harbour, are largely natural, the Outer Harbour is delineated by the man-made East Headland, which has been constructed since 1956 by using largely clean fill from construction projects. The East Headland forms the western boundary of the Main STP area (Figure 1.2) and deflects westerly lake currents southward in the vicinity of the Main STP outfall. Near the Main STP, Ashbridges Bay is a popular area for pleasure boating, and the Eastern Beaches, a popular area for body-contact recreation, stretches eastward to the edge of the Scarborough Bluffs.

1.2.1 Description of the Toronto Main STP

With a capacity of 8.18 x $10^5 m^3$/day, the Toronto Main STP is presently the largest complete sewage treatment plant in Canada, and has an estimated value of approximately $400,000,000.

The initial primary treatment plant was constructed in 1910. Since 1943, the plant has been upgraded in stages, and its ultimate capacity could reach 1.36 x $10^6 m^3$/day before the end of the century. (Gore and Storrie, 1986b).

The wastewater treatment processes at the Toronto Main STP are described briefly here:

- Grit removal and screening - Grit and non-organic material are removed from the wastewater in 16 grit channels. Additional suspended debris are then removed by 14 automatic self-cleaning bar screens. Debris is hauled to a sanitary landfill site.

- Primary settling - Solids in the raw wastewater are settled in 12 primary sedimentation tanks with a total volume of approximately 1.13 x $10^5 m^3$. The resulting sludge is pumped to sludge blending tanks when it is mixed with a pre-selected ratio of digested waste activated sludge, or to anaerobic digestion tanks.

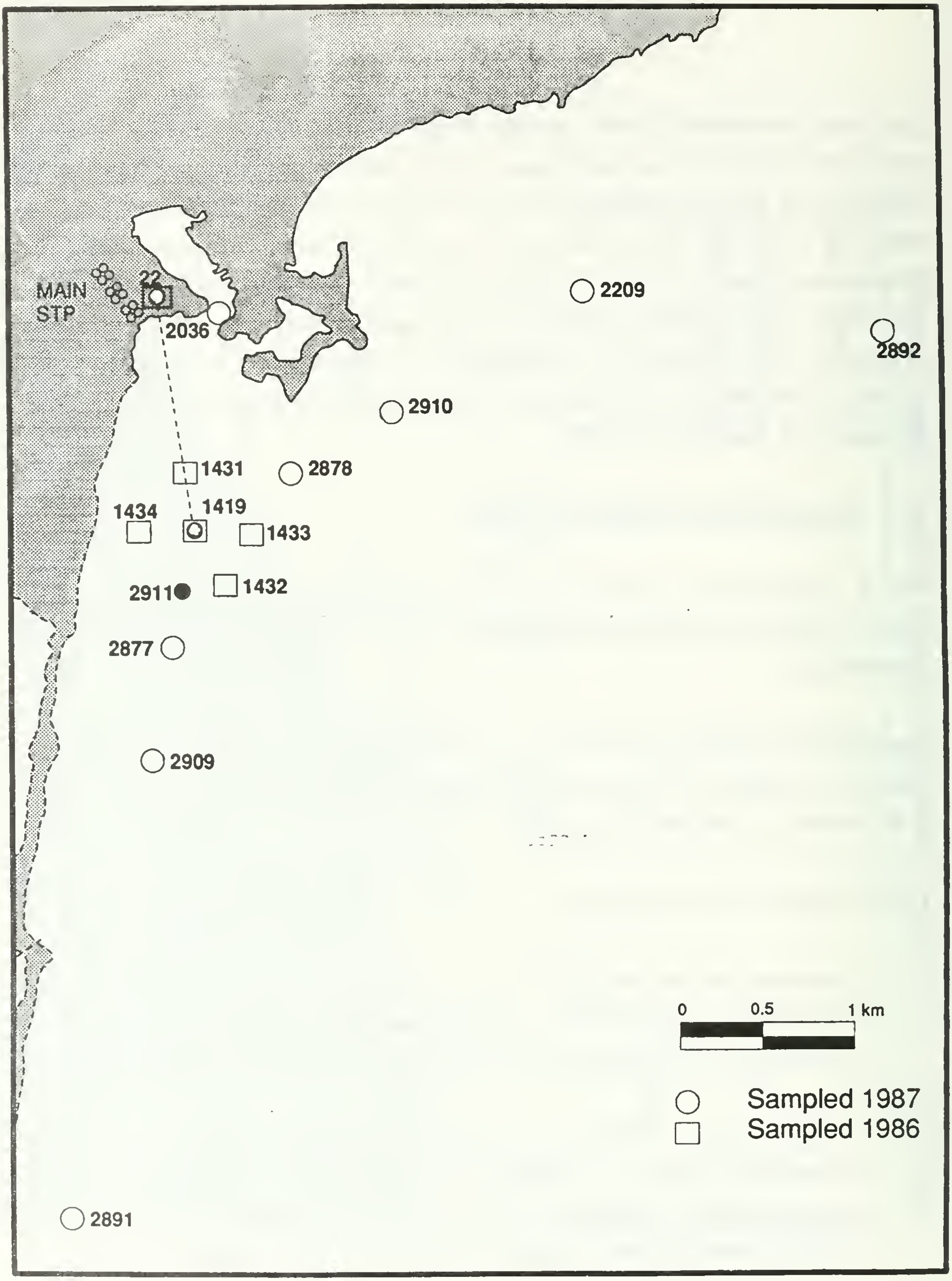


FIGURE 1.2
Main S.T.P. Study
Location of Sampling Stations

- Secondary (activated sludge) treatment - The primary effluent is mixed with return activated sludge and aerated in nine aeration tanks (total volume $1.6 \times 10^5 m^3$), where air from centrifugal blowers is diffused in to provide an aerobic environment for biological growth. The sewage is then settled in nine sedimentation tanks (total volume $1.05 \times 10^5 m^3$). The settled sludge is partially returned to the aeration tanks as a biological seed, while the remainder is pumped back to the head of the plant or to dissolved air flotation tanks for thickening.

- Chlorination - The secondary effluent is disinfected with a chlorine solution, and is then discharged to the lake. Contact time required for chlorination to take effect is provided in the long outfall pipe. Chlorination is utilized only between April 1 and September 30 of each year.

- Sludge treatment - Waste activated sludge is first thickened from about 1% solids to 5% solids in ten dissolved air flotation units. It is then digested for several days in anaerobic digestion tanks at a controlled temperature of about 35°C. The sludge is then conditioned at a temperature of 215°C and a pressure of 2500 kPa in order to break down the sludge cells and release bound water. This thermally conditioned sludge (approximately 12% solids) is then dewatered on rotary drum vacuum filters or stainless steel coil media vacuum filters on belt filter processes. The dewatered sludge cake is then incinerated at approximately 800°C in multiple-hearth incinerators. The resultant ash is removed by a private firm to reclaim the minerals.

Waste gases from the activated sludge treatment or sludge incineration are scrubbed with water including ozone or sodium hypochlorite and exhausted to the atmosphere through a 185 m high stack.

1.2.2 Other Inputs

The following description of inputs to Lake Ontario in Metro Toronto is taken from the draft Stage 1 Toronto Waterfront Remedial Action Plan (RAP, 1988) with minor modifications.

Metro Toronto has an extensive sewer system consisting of combined sewer and storm sewer networks. Storm sewers serve to facilitate efficient overland drainage. Urban storm runoff is conveyed by storm sewers directly to the Metro Waterfront and its tributaries. The volume and rate of flow varies with the duration, intensity and areal extent of storms, and the time interval between each successive event. The locations of major storm and combined sewer outfalls along the central waterfront are shown in Figure 1.3.

Older areas of development within Metropolitan Toronto were initially serviced with combined sewers which were designed to carry both sanitary sewage and stormwater runoff. During dry weather, sanitary sewage is conveyed to area sewage treatment plants (STPs) for treatment. During wet weather, stormwater runoff enters the combined sewers and mixes with the sanitary sewage and is termed combined sewage. During small storms, which do not exceed the capacity of the system, the combined sewage is to be conveyed to the STPs for treatment. Combined sewer overflows (CSO's) occur when the capacity of the system is exceeded. Excess combined sewage is then discharged directly to the receiving waters of the Humber and Don rivers and Lake Ontario. Although the City of Toronto, the City of Scarborough and the Borough of East York have undertaken major storm sewer separation programs, a large portion of the stormwater in older areas still enters combined sewers. The Humber and Don Rivers (mouths at stations 2043 and 1375 respectively) are the two most significant point sources of pollution other than the STPs described below.

Storm and combined sewers may also carry flows during dry weather as a result of minor tributaries, groundwater infiltration, illegal sanitary connections or malfunctioning CSO regulators.

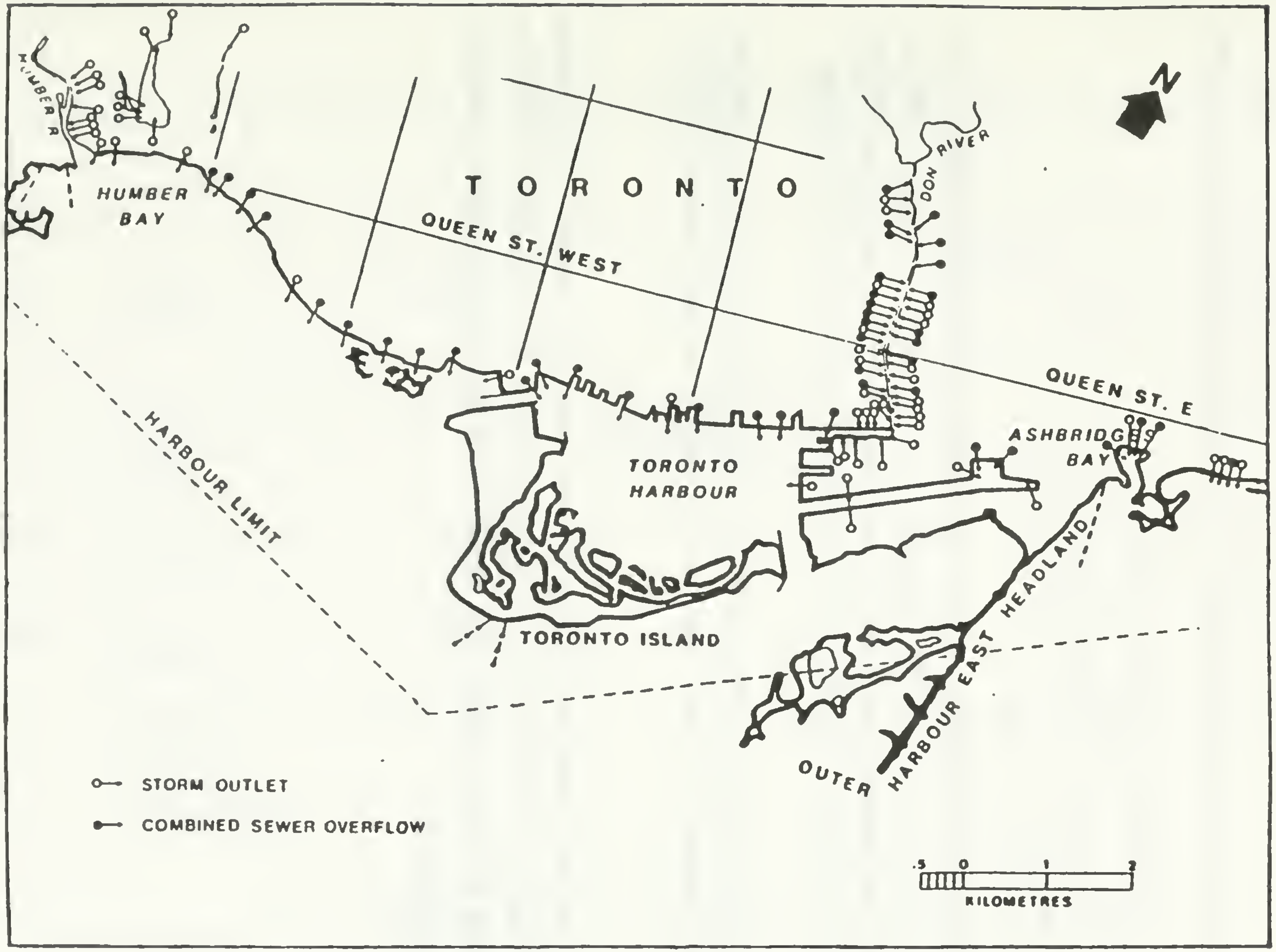


FIGURE 1.3: STORM AND COMBINED SEWER OUTFALLS

Domestic sewage from within the study area is conveyed by sanitary sewers to four STPs:

- Humber STP (outfall station 2072)
- Toronto Main STP (outfall station 1419)
- Highland Creek STP (outfall station 2902)
- North Toronto STP

The Humber, Main and Highland Creek STPs discharge treated effluent directly to Lake Ontario. The North Toronto STP discharges to the Don River. These four STPs are operated by the Regional Municipality of Metropolitan Toronto. The Lakeview STP (63 MGD) lies outside the study area, west of Etobicoke Creek in the city of Mississauga.

The four STPs serving the Toronto area are conventional activated sludge plants with continuous phosphorus removal. Additional information on these plants is provided in Table 1.1.

There are no direct discharges of industrial process waters to the waterfront (only cooling water discharges are allowed), but there are periodic spills of oils and other material into the Spadina and Simcoe Street Slips, probably from the waterfront railway lands and adjacent urban areas.

TABLE 1.1: WATER POLLUTION CONTROL PLANTS - INTAKES AND OUTFALLS IN THE METRO TORONTO WATERSHED

Sewage Treatment Plants (STP)	Area Served	Population Served	Treatment Type	Daily Capacity MGD	Daily Capacity 1000 m^3	Discharge Location
Humber Bay	North York York Etobicoke Vaughan	660,000	Conventional activated sludge & continuous P removal	90	409.1	Lake Ontario
North Toronto	North York Toronto East York	55,000	"	10	45.5	Don River
Highland Creek	Scarborough Markham	290,000	"	48	218.2	Lake Ontario
Main	North York Toronto East York Markham Scarborough	1,200,000	"	180	818.3	Lake Ontario
TOTAL		2,205,900		328	1491.3	

2.0 STUDY OUTLINE AND METHODOLOGY

The water quality component of the Main STP MISA pilot site study consisted of collection of samples from the Main STP effluent as well as the receiving water in Lake Ontario. These were done during a series of intensive sampling periods, each of one to three weeks duration in 1986 and 1987. (Table 2.1).

2.1 1986 Study

The 1986 studies were considered as preliminary to the more detailed work done in 1987. As such, the sampling effort was concentrated in the immediate vicinity of the Main STP outfall (Station 1419, plus stations 1431, 1432, 1433 and 1434, which were located on a circle of 250 m radius centered on the outfall; Figure 1.2). Two "control" stations were located outside the Main STP study area: 1536 (Island WTP intake) and 2029 (R.C. Harris WTP intake) (figure 1.1). All stations near the STP outfall were sampled in duplicate two to three times daily; on most study days only one "control" station was sampled. In addition, an hourly series of six to eight duplicate final effluent grab samples was collected from the manhole prior to discharge to the lake, on the same days as lake water collections.

At each visit to a lake station, a profile for temperature, conductivity and turbidity (as estimated by fluorescence) was first obtained. The duplicate water samples were collected at the surface (generally 0.5 or 1.0 m water depth) and at the bottom (6 m) or depth of turbidity maximum. The depth of turbidity maximum was thought to indicate possibly higher contaminant concentration, as bottom turbidity plumes have frequently been found in previous work (Boyd, 1988).

At the in-plant final effluent sampling location (station 03-0022), station 1419 and 1431 to 1434, a complete set of parameters was collected: general chemistry, bacteriology, heavy metals and toxic organics (PCBs, organochlorine pesticides, chlorobenzenes, chlorophenols, organo- phosphorus insecticides, phenoxy acid herbicides, and volatile organics). At stations 1431 to 1434, only a limited number of general chemistry and bacteriology parameters were sampled.

TABLE 2.1: SAMPLING PERIODS, TORONTO MAIN STP MISA SURVEY

	In-Plant	Lake Ontario
(a) 1986	June 6	June 6
	August 12,13,14	August 12,13,14
	September 8,9,10,11	September 8,9,10,11
	November 4,6,7	November 4,6,7
(b) 1987	June 2-5, 15-19	June 4,7,14 (W) June 3,6,11 (C) June 2,5,10 (E)
	July 28-31	August 1,7,11 (W)
	August 4, 11-12	July 30, August 2,6 (C) July 29, August 4,8 (E)
	October 5-8, 13-16	October 7,11,13 (W-C) October 6,10,12 (C-E)

Note: W = Western portion of waterfront
C = Central portion of waterfront
E = Eastern portion of waterfront

2.2 1987 Study

In 1987, the survey area encompassed the entire Metro Toronto waterfront area (Figures 1.1 and 1.2), in support of both the Main STP MISA study and the Toronto Waterfront RAP. The purposes of this survey were: (a) to provide further baseline data on water quality across the entire Metro Toronto Waterfront area; (b) to update water quality zonation in the Toronto Waterfront; (c) to provide an estimate of zones in non-compliance with PWQO, in order to estimate the extent of loading reductions required, and (d) to provide input for an organic contaminant modelling study being undertaken by Dr. E. Halfon of NWRI (see section 4.3). The survey also included in-plant sampling (daily duplicate grab samples) at each of the four Metro Toronto area STPs discharging to Lake Ontario (Section 1.2), as well as tributary mouth sampling at all Metro area tributaries (section 1.2). Loading information from these components was required for the contaminant model, as well as for the Toronto Waterfront RAP.

Three survey intervals of three weeks' duration were performed; these occurred in June, July-August and October, 1987 (Table 2.1). During each survey, each station was visited on three separate dates; however, two to three days were required to visit all stations once due to the large area and large number of stations to be sampled. This also resulted in profiling activity being limited to a few selected stations. At each station, duplicate samples were collected for general water chemistry, bacteriology and heavy metals. Based on 1986 data (section 3.2.2), only stations closest to dischargers were sampled for organic scans, and these scans were limited to PCBs, organochlorine pesticides and chlorobenzenes. However, a larger range of stations were sampled for organics using ultra-trace methodology (see below). The in-plant effluent samples were also analyzed for PCBs, organochlorines, chlorobenzenes, chlorophenols, triazine herbicides and volatile organics on a series of dates during each of the three survey periods.
Analysis for organic contaminants at ultra-trace levels was also conducted on lake and effluent samples during the three 1987 survey periods. This was required because nearly all the parameters sought in 1986 were rarely if ever, found in the lake water and even only

occasionally in the STP effluent (Sections 3.1.1 and 3.1.2). Quantitative data were also required for model calibration and validation of the fate and transport model (section 4.3).

At about 20 lake stations in each survey period, 200-L of lake water was pumped through a centrifuge into an APLE (Aqueous Phase Liquid-liquid Extractor; Oliver and Nichol, 1986), in which the organic contaminants were extracted into 8 L of dichloromethane and the dichloromethane returned to the laboratory for analysis. On eight dates during the 1987 survey periods, 16 L final effluent samples from the four STPs were also collected (Eli-Eco Laboratories, 1988). Daily composites were obtained by collecting 8 L in the morning and 8 L in the afternoon. These samples were sequentially extracted with three aliquots of dichloromethane, which were then combined for analysis. Analysis of extracts from either the sewage or lake samples involved clean-up and concentration steps followed by analysis using a capillary gas chromatograph with an electron capture detector. Quantification was achieved by correcting the measured results for the recovery of brominated organic compounds with which the samples had been spiked immediately after collection. Further analytical details are given elsewhere (Eli-Eco Laboratories, 1988; Oliver and Nicol, 1986). Field work (on lake) for this portion of the study was done by Lakes Research Branch, NWRI; collection of STP samples and all analytical work was done by B.G. Oliver (Eli-Eco Laboratories) under contract. Similar 200 L samples of tributary water were also collected in August and October 1987 and analyzed under contract by Zenon Laboratories, Burlington, Ontario.

3.0 RESULTS AND DISCUSSION

The results of the 1986-87 Toronto MISA water quality sampling program are discussed along with data obtained in related studies and historical data in this section where appropriate. The discussion is divided into subsections dealing with the Main STP itself, Lake Ontario in the Main STP vicinity, and Lake Ontario across the entire Toronto Waterfront area. The latter section places the relative impact of the Main STP discharge into context with the entire waterfront, and is also important in terms of the Toronto Waterfront RAP.

3.1 Main STP Effluent

This section is primarily concerned with loadings of conventional and toxic pollutants from the Main STP to Lake Ontario as determined during the Great Lakes Section surveys in 1986 and 1987. Additional heavy metal loadings were also obtained from data collected by the MISA Municipal Section (MOE, 1989).

3.1.1 Monthly and Annual Loadings to Lake Ontario

Concentrations of all water quality parameters (conventionals, bacteria, metals and organics) measured during the 1986 and 1987 surveys were multiplied by the effluent flow data corresponding to the time of collection of each effluent sample (nearest 15 minutes in 1986, nearest hour in 1987). These produced time series of 7 to 8 hourly loadings per day in 1986 and duplicate daily results in 1987. Within-day variations in loadings as obtained from 1986 data are discussed in section 3.1.3; in this section, monthly and annual loadings are discussed. These are compared with loadings from the other Toronto-area STP's discharging to Lake Ontario during 1987 in section 3.3.3.

Annual statistics for loadings of conventionals, bacteria, heavy metals and organic compounds (conventional and ultra-trace dectection limits) are given in Tables 3.1 for 1986 and 3.2 for 1987. Data for organic compounds at conventional detection limits are limited to those found in 50% or more of the effluent samples.

For calculation of means and standard deviations in these samples, the maximum likelihood estimator (MLE) method (El-Sharaawi, 1989) was used to estimate the mean loadings and their confidence limits. Other methods of handling such samples as discussed in Appendix 4.

Organic compounds which were infrequently or never detected in the Main STP effluent at conventional detection limits are summarized in Table 3.3. In general, seasonal and short-term variability in effluent loadings (as a result of variations in both flow and concentration) were found to be high; consequently no statistically significant ($P>0.05$) differences were found between years in loadings results.

Loadings for conventionals and heavy metals have been summarized on a monthly basis for the survey months in 1986 and 1987 in Tables 3.4 - 3.10 and for selected parameters in Figure 3.1. Monthly bacterial loadings are summarized in Table 3.1b and 3.2b. Nitrate + nitrite-N was found to be highest during July to September of both years, suggesting some nitrification of effluent during the warmest months; however, the extent of nitrification was very small at any time compared to Lakeview and Highland Creek STPs (section 3.3.3). Total phosphorus, BOD, COD and suspended solids show some tendency towards higher loadings early in the season; however, variability is great. Heavy metal loadings were slightly higher in 1986 than in 1987, but variability in 1986 was greater. Bacteria loadings during fall post-chlorination periods (November 1986 and October 1987) are one to three orders of magnitude higher than for the other survey months, as expected for chlorine disinfection; the difference was greatest for fecal coliforms and E. coli. Unexpectedly, high bacterial loadings were found on some dates in September 1986 (Table 3.1b); the reason for this is unknown.

TABLE 3.1(a): LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, ANNUAL MEANS, JUNE - NOVEMBER 1986

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1260	210	790	2080	75
(a) Conventionals (10^3 kg/day)					
NH_3-N	26.0	7.4	7.0	42.6	148
TKN	30.8	8.8	10.0	63.8	148
(NO_2+NO_3)-N	1.31	1.70	0.06	7.3	148
Total P	1.29	2.20	0.23	12.5	148
Total Dissolved Solids*	776.	135.	488.	1221.	90
Suspended Solids	30.4	53.0	3.1	338.	140
BOD	15.9	17.1	0.4	81.	126
COD	51.9	21.5	20.3	132.	119
DOC	14.3	4.3	0.12	27.1	142
Phenols (kg/day)	5.8	5.7	1.9	34.	129
Cyanide (kg/day)	14.2	17.	41.	108.	126
(b) Heavy Metals (kg/day)					
Cadmium	1.3	31.8	0.	11.	146
Chromium	37.	49.	1.	282.	146
Copper	41.	57.	1.	290.	146
Iron	1300.	2000.	37.	12400.	146
Mercury (g/day)	107.	136.	11.	700.	146
Manganese	68.	18.	1.	135.	146
Nickel	33.	13.	2.	68.	146
Lead	15.	21.	<3.	118.	135
Zinc	88.	116.	1.	614.	146

* Estimated as conductivity (25°C) x 0.65

TABLE 3.1(b): **BACTERIAL LOADINGS (organisms/day)**
MAIN STP, 1986

PARAMETER	N	GEOM. MEAN	SD LOWER	SD UPPER	MIN	MAX
(a) **Whole year**						
Aug.-Nov.						
Fecal coliforms	137	9.3×10^{13}	6.1×10^{12}	1.4×10^{15}	1.4×10^{12}	1.0×10^{17}
E. coli	137	6.3×10^{13}	3.5×10^{12}	1.1×10^{15}	1.2×10^{12}	9.9×10^{16}
Fecal streptococci	136	6.0×10^{13}	1.1×10^{13}	3.2×10^{14}	5.8×10^{11}	7.2×10^{15}
P. aeruginosa	122	8.1×10^{11}	1.3×10^{11}	5.0×10^{12}	2.2×10^{10}	3.0×10^{13}
(b) **August**						
Fecal coliforms	40	1.1×10^{13}	3.7×10^{12}	3.4×10^{13}	2.4×10^{12}	4.7×10^{14}
E. coli	40	4.9×10^{12}	1.5×10^{12}	1.6×10^{13}	1.2×10^{1}	5.1×10^{13}
Fecal streptococci	40	2.5×10^{13}	4.7×10^{12}	1.3×10^{14}	5.8×10^{11}	4.6×10^{14}
P. aeruginosa	40	1.7×10^{11}	4.1×10^{10}	6.6×10^{11}	2.2×10^{10}	2.3×10^{12}
(c) **September**						
Fecal Coliforms	58	7.2×10^{13}	4.0×10^{12}	1.3×10^{15}	1.4×10^{12}	1.0×10^{17}
E. coli	58	5.6×10^{13}	3.0×10^{12}	1.0×10^{15}	1.2×10^{12}	9.0×10^{16}
Fecal streptococci	58	6.9×10^{13}	1.2×10^{13}	4.0×10^{14}	8.7×10^{12}	7.2×10^{15}
P. aeruginosa	44	1.2×10^{12}	2.0×10^{11}	7.2×10^{12}	4.4×10^{10}	3.0×10^{13}
(d) **November***						
Fecal coliforms	39	1.2×10^{15}	4.8×10^{14}	3.0×10^{15}	1.7×10^{14}	4.7×10^{15}
E. coli	39	1.0×10^{15}	4.1×10^{14}	2.7×10^{15}	1.3×10^{14}	3.9×10^{15}
Fecal streptococci	38	1.2×10^{14}	4.2×10^{13}	3.6×10^{14}	1.7×10^{13}	6.9×10^{14}
P. aeruginosa	38	2.8×10^{12}	1.2×10^{12}	6.3×10^{12}	4.6×10^{11}	1.1×10^{13}

Note * - effluent not chlorinated

TABLE 3.1(c): LOADINGS OF ORGANIC COMPOUNDS (CONVENTIONAL DETECTION LEVELS), MAIN STP, ANNUAL MEANS, JUNE - NOVEMBER 1986 (g/day)

	MLE ESTIMATES			OBSERVED			
		CONF. INT.					
PARAMETER	MEAN	MIN	MAX	MEDIAN	MAX	N	%
Dichloromethane	14700.	7400.	29000.	8400.	58000.	28	79
Chloroform	4700.	2800.	7900.	2600.	29000.	28	71
γ-BHC (Lindane)	35.	19.	66.	22.	88.	34	79
1,2,4-Trichlorobenzene	228.	70.	740.	75.	290.	33	73
1,2,3-Trichlorobenzene	105.	43.	250.	51.	330.	34	74
1,2,3,4-Tetrachlorobenzene	58.	33.	100.	34.	91.	34	85
Pentachlorobenzene	20.	10.	44.	11.	60.	34	70
2,4,6-Trichlorophenol	165.	115.	240.	140.	700.	36	72
2,3,4,5-Tetrachlorophenol	102.	71.	150.	55.	1290.	36	50
Pentachlorophenol	490.	330.	730.	360.	1900.	26	88
Diazinon	230.	180.	290.	230.	370.	17	100

Note: % - percent of effluent samples in which the indicated constituent was detected (including samples reported as "trace" - <T)

TABLE 3.2(a): **LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, ANNUAL MEANS, JUNE - OCTOBER 1987**

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	960	250	560	1730	48
(a) Conventionals (10^3 kg/day)					
NH_3-N	20.0	6.5	8.9	34.6	47
TKN	24.1	6.9	12.3	37.1	45
(NO_2+NO_3)-N	0.86	2.19	0.03	110.	48
Total P	0.79	1.69	0.10	10.89	47
Total Dissolved Solids*	573.	142.	355.	961.	47
Total Filtered Residue	475.	122.	275.	734.	46
Suspended Solids	27.1	75.6	3.3	398.	47
COD	87.2	81.0	33.9	442.	41
DOC	13.4	3.4	6.1	21.1	47
(b) Heavy metals (kg/day)					
Chromium	22.	14.	6.	74.	46
Copper	16.	15.	0.	55.	46
Iron	980.	670.	270.	3700.	46
Mercury (g/day)	39.	23.	10.	117.	46
Manganese	70.	22.	36.	124.	46
Nickel	34.	13.	17.	65.	46
Lead	9.	10.	0.	34.	46
Zinc	34.	39.	0.	94.	46

* Estimated as conductivity (25°C) x 0.65

TABLE 3.2(b): **BACTERIAL LOADINGS (organisms/day), MAIN STP, 1987**

PARAMETER	N	GEOM. MEAN	SD LOWER	SD UPPER	MIN	MAX
(a) Whole year						
Fecal coliforms	46	$2.8x10^{13}$	$8.7x10^{11}$	$9.5x10^{14}$	$2.0x10^{11}$	$1.7x10^{16}$
E. coli	46	$2.0x10^{13}$	$5.3x10^{11}$	$7.7x10^{14}$	$1.7x10^{11}$	$1.5x10^{16}$
Fecal streptococci	46	$1.1x10^{13}$	$7.6x10^{11}$	$1.8x10^{14}$	$4.5x10^{10}$	$9.8x10^{14}$
Heterotrophs	10	$6.3x10^{14}$	$2.1x10^{14}$	$1.8x10^{15}$	$1.1x10^{14}$	$1.9x10^{15}$
P. aeruginosa	46	$5.0x10^{11}$	$4.3x10^{10}$	$5.8x10^{12}$	$2.4x10^{10}$	$6.0x10^{13}$
(b) June						
Fecal coliforms	16	$1.1x10^{13}$	$1.4x10^{12}$	$9.7x10^{13}$	$1.9x10^{12}$	$2.2x10^{15}$
E. coli	16	$9.5x10^{12}$	$1.2x10^{12}$	$7.6x10^{13}$	$1.6x10^{12}$	$1.6x10^{15}$
Fecal streptococci	16	$1.9x10^{13}$	$5.8x10^{12}$	$6.5x10^{13}$	$2.7x10^{12}$	$3.1x10^{14}$
Heterotrophs	10	$6.3x10^{14}$	$2.1x10^{14}$	$1.8x10^{15}$	$1.1x10^{14}$	$1.9x10^{15}$
P. aeruginosa	16	$4.7x10^{11}$	$5.3x10^{10}$	$4.1x10^{12}$	$4.1x10^{10}$	$5.7x10^{13}$
(c) July-August						
Fecal Coliforms	14	$1.0x10^{12}$	$3.9x10^{11}$	$2.6x10^{12}$	$2.0x10^{11}$	$4.9x10^{12}$
E. coli	14	$5.2x10^{11}$	$2.1x10^{11}$	$1.3x10^{12}$	$1.7x10^{11}$	$2.7x10^{12}$
Fecal streptococci	14	$4.6x10^{11}$	$1.2x10^{11}$	$1.7x10^{12}$	$4.5x10^{10}$	$2.7x10^{12}$
P. aeruginosa	14	$5.3x10^{10}$	$2.7x10^{10}$	$1.1x10^{11}$	$2.4x10^{10}$	$1.7x10^{11}$
(d) October*						
Fecal coliforms	16	$1.3x10^{15}$	$1.7x10^{14}$	$1.1x10^{16}$	$6.4x10^{13}$	$1.7x10^{16}$
E. coli	16	$1.1x10^{15}$	$1.2x10^{14}$	$9.8x10^{15}$	$4.6x10^{13}$	$1.5x10^{16}$
Fecal streptococci	16	$1.2x10^{14}$	$1.9x10^{13}$	$7.9x10^{14}$	$7.8x10^{12}$	$9.8x10^{14}$
P. aeruginosa	16	$3.8x10^{12}$	$5.4x10^{11}$	$2.7x10^{13}$	$4.1x10^{11}$	$6.0x10^{13}$

Note * - effluent not chlorinated

TABLE 3.2(c): LOADINGS OF ORGANIC COMPOUNDS (CONVENTIONAL DETECTION LEVELS), MAIN STP, ANNUAL MEANS, JUNE - OCTOBER 1987 (g/day)

PARAMETER	MLE ESTIMATES MEAN	CONF. INT. MIN	CONF. INT. MAX	OBSERVED MEDIAN	OBSERVED MAX	N	%
α-BHC	4.1	1.5	11.	1.6	26.	20	60
γ-BHC (Lindane)	41.	26.	65.	35.	78.	20	95
1,2,3-trichlorobenzene	37.	2.6	530.	13.	81.	20	55
1,2,4-trichlorobenzene	28.	1.0	800.	15.	73.	20	55
1,2,3,4-tetrachlorobenzene	31.	7.7	126.	13.	63.	19	74
pentachlorobenzene	5.9	3.2	11.	3.9	18.	20	75
hexachlorobenzene	5.3	1.8	16.	1.2	31.	19	63
2,4,6-trichlorophenol	71.	38.	132.	42.	200.	18	83
pentachlorophenol	160.	80.	320.	62.	820.	18	95
chloroform	2700.	2100.	3600.	2400.	9300.	44	86
dichloromethane	5300.	4100.	6800.	4500.	13000.	44	89

Note: % - percent of effluent samples in which the indicated consituent was detected.

TABLE 3.2(d): LOADINGS OF ULTRA-TRACE ORGANIC COMPOUNDS MAIN STP, ANNUAL MEANS, 1987 (g/day)

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N	DETECT. LIMIT (ng/L)	% OF SAMPLES DETECTED
1,3-dichlorobenzene	78.	38.	25.	155.	10	1	100
1,4-dichlorobenzene	630.	260.	100.	990.	10	1	100
1,2-dichlorobenzene	280.	130.	63.	480.	10	1	100
1,3,5-trichlorobenzene	2.5	2.1	0.4	7.4	10	0.1	100
1,2,4-trichlorobenzene	116.	118.	15.	350.	10	0.1	100
1,2,3-trichlorobenzene	54.	79.	6.1	210.	10	0.1	100
1,2,3,5-tetrachlorobenzene	9.2	15.8	0.1	42.	10	0.05	100
1,2,4,5-tetrachlorobenzene	19.	15.	4.3	47.	10	0.05	100
1,2,3,4-tetrachlorobenzene	68.	101.	12.	271.	10	0.05	100
pentachlorobenzene	6.9	5.1	0.	17.	10	0.02	80
hexachlorobenzene	4.1	6.1	0.	17.	10	0.02	80
hexachloroethane	0.16	0.33	0.	1.1	10	0.02	50
2,4,5-trichlorotoluene	0.80	2.2	0.	0.70	10	0.1	50
2,3,6-trichlorotoluene	0.25	0.42	0.	1.2	10	0.1	40
pentachlorotoluene	0.67	0.84	0.	2.7	10	0.02	70
α-BHC	1.3	0.8	0.	2.5	10	0.02	90
γ-BHC (lindane)	21.	17.	0.	50.	10	0.02	70
heptachlor + heptachlor epoxide	0.11	0.17	0.	0.49	10	0.02	40
endosulfan - I	0.42	0.43	0.	1.3	10	0.02	60
endosulfan - II	0.10	0.22	0.	0.63	10	0.02	20
γ-chlordane	0.34	0.18	0.	0.67	10	0.02	90
α-chlordane	0.43	0.42	0.	1.3	10	0.02	70
nonachlor	0.27	0.24	0.	0.79	10	0.02	70
pp-DDE	0.62	0.42	0.	1.5	10	0.02	90
pp-DDD	0.37	0.64	0.	2.1	10	0.02	60
op-DDT	0.13	0.32	0.	1.0	10	0.02	20
Total PCB	16.8	10.3	4.7	40.	10	0.05	100

TABLE 3.3: ORGANIC PARAMETERS SELDOM OR NEVER DETECTED AT CONVENTIONAL DETECTION LEVELS, MAIN STP, 1986

PARAMETER	DETECTION LIMIT (ng/L)	FREQ. OF DETECTION (%)	MAXIMUM CONCENT. (ng/L)	N
(a) PCBs, organochlorine pesticides				
Total PCB	20	0	-	29
Hexachlorobenzene	1	43	6	29
Heptachlor	1	0	-	29
Aldrin	1	0	-	29
pp-DDE	1	20	4	29
op-DDT	5	0	-	29
pp-DDD	5	0	-	29
pp-DDT	5	0	-	29
Mirex	5	0	-	29
α-BHC	1	13	2	29
ß-BHC	1	7	5	29
α-chlordane	2	3	22	29
γ-chlordane	2	7	20	29
Oxychlordane	2	0	-	29
DMDT-methoxychlor	5	0	-	29
Heptachlor epoxide	1	0	-	29
Endosulfan I	2	0	-	29
Endosulfan II	4	13	14	29
Endosulfan Sulfate	4	0	-	29
Dieldrin	2	3	6	29
Endrin	4	7	8	29
(b) Chlorobenzenes				
Hexachloroethane	1	27	17	30
1,3,5-Trichlorobenzene	5	17	17	30
2,4,5-Trichlorotoluene	5	0	-	30
2,3,6-Trichlorotoluene	5	0	-	30
Hexachlorobutadiene	1	0	-	30
1,2,3,5-Tetrachlorobenzene	1	23	30	30
1,2,4,5-Tetrachlorobenzene	1	23	40	30
2,6,a-Trichlorotoluene	5	0	-	30
(c) Chlorophenols				
2,4,5-Trichlorophenol	50	3	50	30
2,3,4-Trichlorophenol	100	3	120	30
2,3,5,6-Tetrachlorophenol	50	27	1600	30

TABLE 3.3: (cont'd)

PARAMETER	DETECTION LIMIT (ng/L)	FREQ. OF DETECTION (%)	MAXIMUM CONCENT. (ng/L)	N
(d) Phenoxyacid Herbicides				
Dicamba	100	7	110 T	30
2,4-D-propionic acid	100	13	110 T	30
2,4-Dichlorophenoxyacetic acid	100	30	480 T	30
Silvex	50	0	-	30
2,4,5-Trichlorophenoxyacetic acid	50	10	70 T	30
2,4-Dichlorophenoxybutyric acid	200	37	360	30
Picloram	100	0	-	30
(e) Organophosphorus Insecticides				
Dichlorovos	20	0	-	16
Dursban	20	0	-	16
Ethion	20	0	-	16
Guthion	1000	0	-	16
Malathion	20	0	-	16
Mevinphos	20	0	-	16
Methylparathion	20	0	-	16
Methyltrithion	20	0	-	16
Parathion	20	0	-	16
Phorate	20	0	-	16
Reldan	20	0	-	16
Ronnel	20	0	-	16
(f) Carbamate Herbicides				
Carbofuran	2000	0	-	18
CIPC	2000	0	-	18
Diallate	2000	0	-	18
Eptam	2000	0	-	18
IPC	2000	0	-	18
Propoxur	2000	0	-	18
Sevia	2000	0	-	18
Sutan	2000	0	-	18

Note: T - Trace (<T)

TABLE 3.3: (cont'd)

PARAMETER	DETECTION LIMIT (ng/L)	FREQ. OF DETECTION (%)	MAXIMUM CONCENT. (ng/L)	N
(g) Volatile Organics				
1,1-Dichloroethylene	1	0	-	24
TRS-1,2-Dichloroethylene	1	0	-	24
1,1-Dichloroethane	1	0	-	24
1,1,1-Trichloroethane	1	24	2 T	24
1,2-Dichloroethane	1	0	-	24
Carbon Tetrachloride	1	0	-	24
Benzene	1	5	1 T	24
Trichloroethylene	1	0	-	24
Dichlorobromomethane	1	0	-	24
Toluene	1	10	17	24
1,1,2-Trichloroethane	1	0	-	24
Chlorodibromomethane	1	0	-	24
Chlorobenzene	1	0	-	24
Ethylbenzene	1	0	-	24
m- and p- Xylenes	1	14	75	24
O-Xylene	1	14	17	24
Bromoform	1	0	-	24
1,1,2,2,-Tetrachloroethane	1	14	3 T	24
1,4-Dichlorobenzene	1	14	2 T	24
1,3-Dichlorobenzene	1	33	8 T	24
1,2-Dichlorobenzene	1	5	1 T	24

Note: T - trace (<T)

TABLE 3.4: LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, JUNE 1986

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1190.	50.	1130.	1250.	7
(a) Conventionals (10^3 kg/day)					
NH_3-N	28.8	2.2	25.1	32.6	10
TKN	33.6	3.2	28.1	40.2	10
(NO_2+NO_3)-N	0.06	0.01	0.05	0.07	10
Total P	0.92	0.08	0.75	1.01	10
Total Dissolved Solids*	792.	36.	744.	854.	10
Suspended Solids	27.4	3.4	23.4	35.1	10
DOC	21.4	3.2	16.2	25.2	10
(b) Heavy Metals (kg/day)					
Cadmium	1.3	0.4	1.0	2.0	10
Chromium	38.	3.	35.	46.	10
Copper	52.	9.	35.	66.	10
Iron	1900.	300.	1600.	2700.	10
Mercury (g/day)	117.	44.	90.	234.	10
Manganese	61.	4.	57.	70.	10
Nickel	39.	6.	34.	50.	10
Zinc	64.	6.	56.	78.	10

* Estimated as conductivity (25°C) x 0.65

TABLE 3.5: LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, AUGUST 1986

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1200.	180.	790.	1600.	20
(a) Conventionals (10^3 kg/day)					
NH_3-N	24.1	4.0	16.9	30.3	40
TKN	27.9	4.5	18.3	34.6	40
(NO_2+NO_3)-N	2.06	1.87	0.49	6.7	40
Total P	2.36	2.57	0.45	12.5	40
Total Dissolved Solids*	683.	101.	488.	883.	24
Suspended Solids	54.2	53.6	10.8	195.	40
BOD	26.6	12.3	9.0	49.3	32
COD	73.6	30.3	47.5	132.	21
DOC	12.2	3.7	0.1	17.7	34
Phenols (kg/day)	7.0	4.1	2.8	18.	40
Cyanide (kg/day)	21.	26.	1.	108.	30
(b) Heavy Metals (kg/day)					
Cadmium	2.0	2.2	0.	11.	40
Chromium	53.	46.	1.	194.	40
Copper	80.	54.	1.	228.	40
Iron	1700.	1600.	37.	7200.	40
Mercury (g/day)	191.	153.	63.	637.	38
Manganese	67.	20.	1.	102.	40
Nickel	41.	12.	2.	63.	40
Lead	20.	19.	3.	74.	40
Zinc	118.	109.	1.	423.	40

* Estimated as conductivity (25°C) x 0.65

TABLE 3.6: LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, SEPTEMBER 1986

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1340.	250.	1110.	2080.	28
(a) Conventionals (10^3 kg/day)					
NH_3-N	22.8	9.1	7.0	42.6	58
TKN	28.0	11.5	10.0	63.8	58
(NO_2+NO_3)-N	1.45	1.88	0.11	7.3	58
Total P	1.29	2.55	0.27	11.5	58
Total Dissolved Solids*	684.	58.	628.	837.	16
Suspended Solids	34.5	67.4	5.4	338.	58
BOD	16.3	21.7	0.4	81.	54
COD	47.7	19.3	20.3	104.	58
DOC	13.2	4.1	9.2	27.1	58
Phenols (kg/day)	6.6	7.9	2.0	34.	52
Cyanide (kg/day)	4.6	3.5	1.	16.	54
(b) Heavy Metals (kg/day)					
Cadmium	1.1	2.0	0.	10.	57
Chromium	38.	65.	9.	282.	57
Copper	32.	68.	5.	290.	57
Iron	1400.	2900.	300.	12400.	57
Mercury (g/day)	89.	157.	11.	700.	58
Manganese	68.	20.	48.	135.	57
Nicke	126.	13.	8.	68.	57
Lead	19.	26.	3.	118.	56
Zinc	74.	135.	1.	614.	57

* Estimated as conductivity (25°C) x 0.65

TABLE 3.7: **LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, NOVEMBER 1986**

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1250.	210.	890.	1800.	20
(a) Conventionals (10^3 kg/day)					
NH_3-N	32.0	3.5	22.1	39.6	40
TKN	37.0	4.1	25.2	47.2	40
(NO_2+NO_3)-N	0.67	0.87	0.18	5.5	40
Total P	0.32	0.05	0.23	0.43	40
Total Dissolved Solids*	865.	131.	579.	1220.	40
Suspended Solids	6.4	1.5	3.1	9.3	40
BOD	6.9	1.7	1.3	9.9	40
COD	46.7	8.5	28.6	64.9	40
DOC	16.0	2.2	11.1	22.2	40
Phenols (kg/day)	3.3	0.6	1.9	4.6	37
Cyanide (kg/day)	19.1	13.3	4.	65.	40
(b) Heavy Metals (kg/day)					
Cadmium	0.6	0.1	0.0	1.0	39
Chromium	18.	10.	11.	60.	39
Copper	11.	2.	7.	18.	39
Iron	600.	100.	500.	900.	39
Mercury (g/day)	52.	16.	25.	86.	40
Manganese	70.	14.	46.	108.	39
Nickel	32.	8.	18.	47.	39
Lead	< 4.	0.6	< 3.	5.	39
Zinc	83.	103.	20.	469.	39

* Estimated as conductivity (25°C) x 0.65

TABLE 3.8: LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, JUNE 1987

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	910.	170.	560.	1120.	18
(a) Conventionals (10^3 kg/day)					
NH_3-N	18.5	3.9	10.2	23.5	17
TKN	23.5	6.3	12.3	39.0	18
(NO_2+NO_3)-N	0.15	0.19	0.03	0.79	18
Total P	1.19	2.63	0.17	10.89	18
Total Dissolved Solids*	579.	109.	356.	750.	17
Total Filtered Residue	507.	119.	300.	704.	17
Suspended Solids	50.2	119.	5.2	398.	18
COD	112.	121.	37.	442.	17
DOC	14.0	3.1	8.7	19.7	17
(b) Heavy Metals (kg/day)					
Chromium	16.	5.	9.	22.	16
Copper	16.	3.	0.	11.	16
Iron	1050.	280.	600.	1640.	16
Mercury (g/day)	31.	7.	21.	45.	16
Manganese	89.	18.	62.	124.	16
Nickel	28.	9.	17.	45.	16
Lead	1.3	5.	30.	21.	16
Zinc	16.	9.	0.	34.	16

* Estimated as conductivity (25°C) x 0.65

TABLE 3.9: LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, JULY-AUGUST 1987

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	1090.	330.	610.	1730.	14
(a) Conventionals (10^3 kg/day)					
NH_3-N	19.2	7.9	8.9	34.6	14
TKN	22.3	6.7	12.5	37.1	13
(NO_2+NO_3)-N	2.49	3.63	0.67	11.1	14
Total P	0.22	0.12	0.10	0.42	14
Total Dissolved Solids*	615.	180.	355.	961.	14
Total Filtered Residue	486.	138.	275.	734.	14
Suspended Solids	6.6	3.6	3.3	14.2	14
COD	68.	22.	34.	98.	9
DOC	11.7	3.7	6.1	18.8	14
(c) Heavy Metals (kg/day)					
Chromium	18.	9.	6.	35.	14
Copper	28.	13.	10.	52.	14
Iron	640.	370.	270.	1300.	14
Mercury (g/day)	24.	13.	10.	52.	14
Manganese	68.	22.	36.	104.	14
Nickel	31.	13.	18.	65.	14
Lead	14.	14.	0.	34.	14
Zinc	19.	19.	0.	52.	14

* Estimated as conductivity (25°C) x 0.65

TABLE 3.10: **LOADINGS OF CONVENTIONALS AND HEAVY METALS, MAIN STP, OCTOBER 1987**

PARAMETER	MEAN	STD. DEV.	MIN	MAX	N
Flow ($10^3 m^3$/day)	900.	210.	620.	1210.	16
(a) Conventionals (10^3 kg/day)					
NH_3-N	22.4	7.0	12.8	32.5	16
TKN	26.8	7.6	15.7	38.0	13
(NO_2+NO_3)-N	0.21	0.14	0.03	0.51	16
Total P	0.85	0.65	0.14	2.32	15
Total Dissolved Solids*	530.	132.	374.	748.	16
Total Filtered Residue	428.	102.	297.	594.	15
Suspended Solids	18.5	21.1	5.9	70.	15
COD	70.6	23.0	38.0	120.	15
DOC	14.2	3.2	10.6	21.2	16
(b) Heavy Metals (kg/day)					
Chromium	32.	18.	17.	74.	16
Copper	18.	16.	7.	55.	16
Iron	1200.	1000.	500.	3700.	16
Mercury (g/day)	61.	24.	35.	117.	16
Manganese	53.	10.	41.	73.	16
Nickel	42.	13.	26.	62.	16
Lead	12.	6.	7.	25.	16
Zinc	66.	51.	14.	194.	16

* Estimated as conductivity (25°C) x 0.65

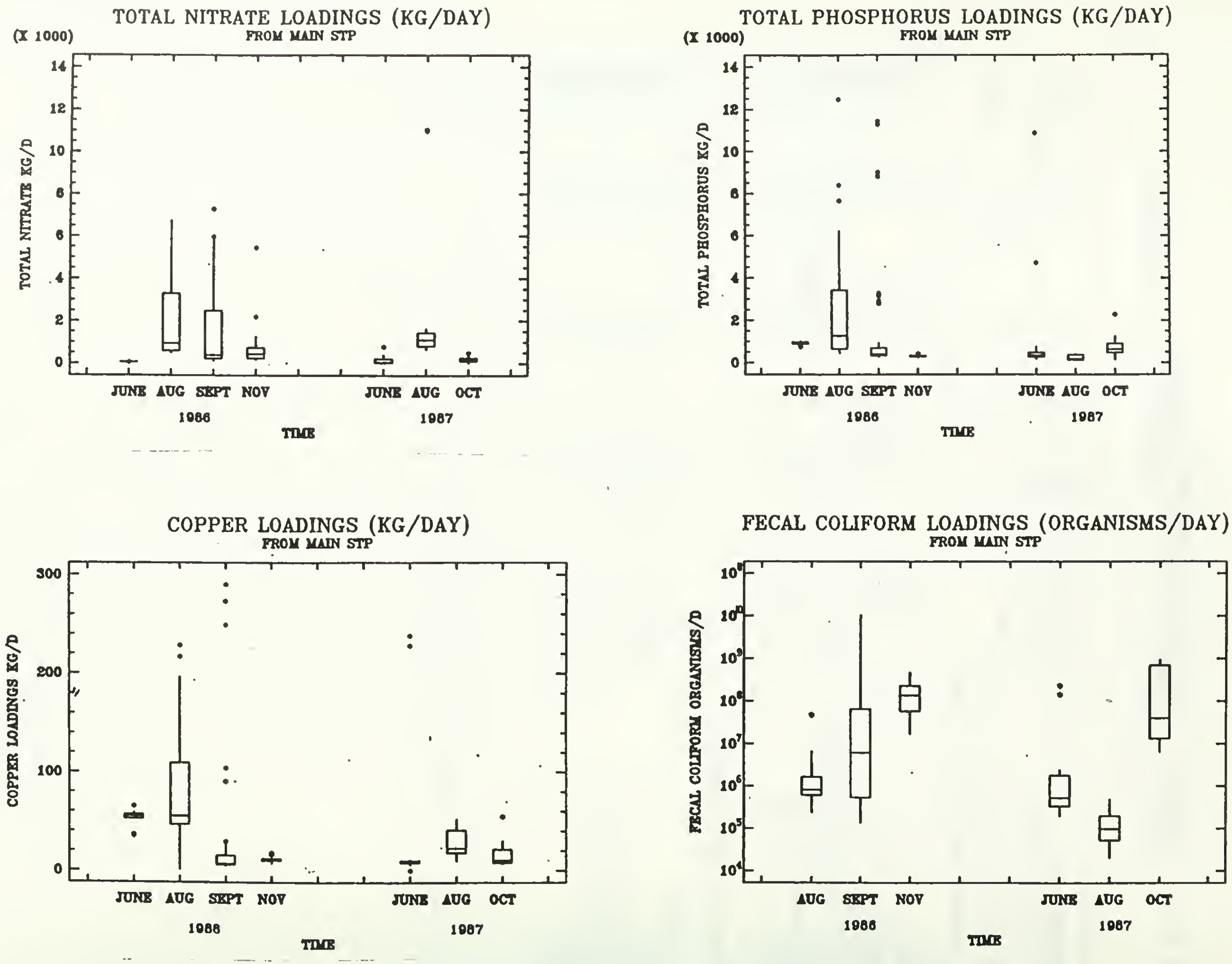


FIGURE 3.1 Monthly loadings of selected parameters Toronto Main STP, 1986-87.

Additional loadings data for heavy metals were available from a 37-STP pilot monitoring study (MOE, 1989). The results of that study are compared to the present results in Table 3.11. For most metals, the present study showed higher loadings; however, nickel loadings were similar and chromium loadings were lower. The latter study also included removal efficiencies; it is seen that these are 90% or higher except for chromium (69%) and nickel (63%). Metal loadings from the Main STP were the highest of all STPs studied, likely due to the large throughput of sewage. However, for most metals, Main STP shows a higher than average removal efficiency compared to the other eight STPs for which detailed information was available; the lower removal efficiencies for chromium and nickel were about average. Mass balance studies in the same report showed that most of the metal removed was present in the sludge; they also concluded that variability in removal efficiencies between metals was likely due to differences in metal chemistry and biochemistry.

3.1.2 Probability Statistics

As is evident from the data presented in section 3.1.1, loadings of chemicals (conventionals or trace contaminants) from the Main STP are highly variable in nature. This section presents additional data on loading variability. This is important for two purposes: (1) Investigators working on toxicity studies, either in-situ or using laboratory serial dilutions of final effluent, need to know under what conditions their experiments were conducted - i.e. were they using an average concentration or perhaps one whose concentration was higher than that observed 95% of the time; and (2) load allocation procedures to be developed based upon effluent limits derived from various studies must relate to this loading variability. For the purposes of load allocation, the allowable load is considered to be the load for which the defined objective will be satisfied for a specified fraction of the time at the edge of the mixing zone, given the statistical variability of effluent quality. The water quality-based effluent limits were derived on the basis of 95% compliance with objectives - i.e. effluent quality must not be out of compliance more than 5% of the time on a monthly average basis. From the various models used in their studies, they produced

TABLE 3.11: COMPARATIVE HEAVY METAL LOADINGS (kg/day), TORONTO MAIN STP

METAL	THIS STUDY 1986	THIS STUDY 1987	MOE, 1989 LOADING	MOE, 1989 % REMOVAL
Cr	37	31	58	68.8
Cu	41	26	8	92.2
Hg (g/day)	107	64	31	92.2
Ni	33	34	27	63.2
Pb	-	12	8	89.5
Zn	88	56	23	93.3

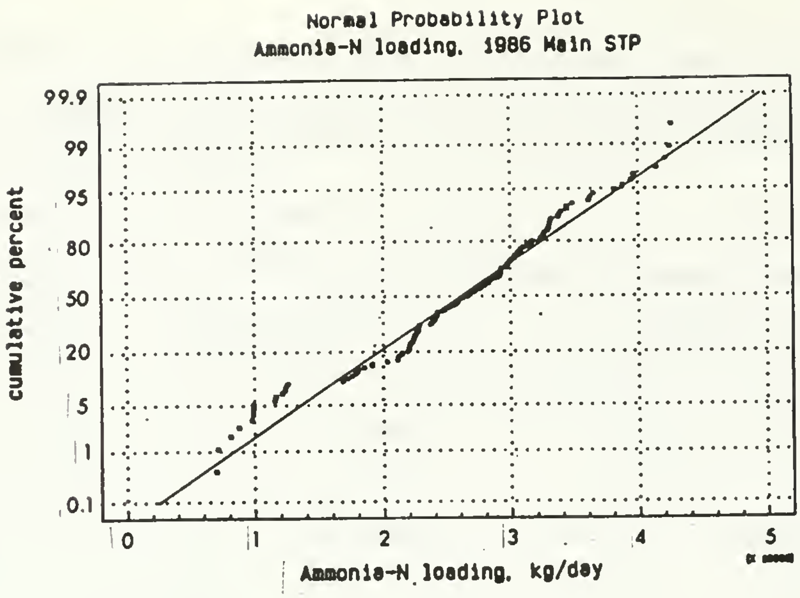
cumulative probability curves for loadings of various parameters, from which the fraction of non-compliance for any given load reduction scenario could be obtained.

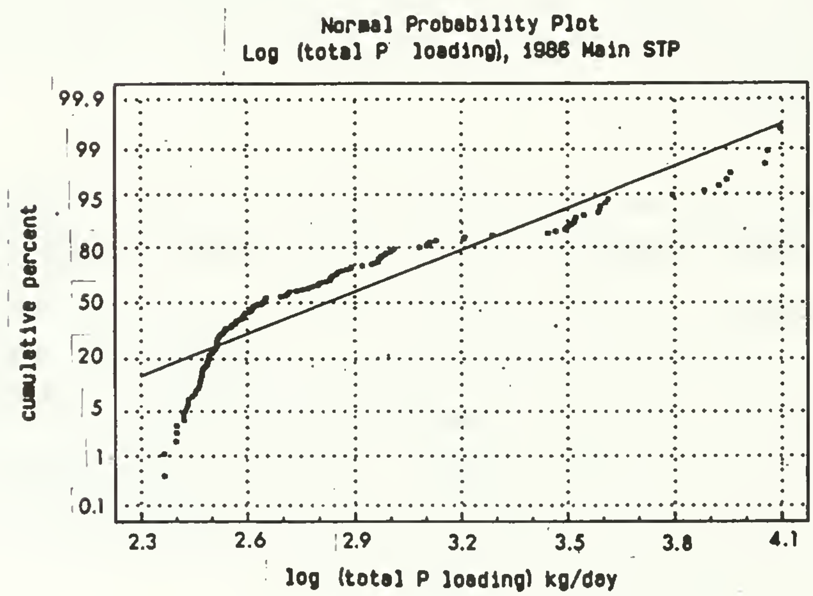
For conventional parameters, ammonia-N, total P and suspended solids were chosen, and probability plots for these parameters are presented for 1986 in Figure 3.2 and for 1987 in Figure 3.3. Total P and suspended solids are plotted as logarithmic transformations; as the distribution of ammonia is approximately normal, no transformation was required. The y-axis of each figure represents the percent of observation above the specified point on the line - i.e. if one desires the 95th percentile ammonia loading (the loading exceeded by 5% of observations), this value is 3.8×10^4 kg/d in 1986 (Figure 3.2) and 3.0×10^4 kg/d in 1987 (Figure 3.3). It should be noted that the minima and maxima of all parameters reflect the values given in Tables 3.1(a) and 3.2(a); in addition, the median loading (not given in the tables) is equal to the 50th percentile value, 2.6×10^4 and 2.0×10^4 kg/d for ammonia in 1986 and 1987, respectively.

Similar plots for several important heavy metals in 1987 are reproduced in Figures 3.4. All data were logarithmically transformed; usage of these plots is similar to that for conventionals. It should be noted that probability plots for two toxicologically important metals - cadmium and lead - were not prepared as most of the data were below detection for these metals. As for conventionals, a large range of loadings, due to the range in both concentration and flow, is evident from the figures. However, use of these figures will allow a clear perspective of the relative conditions occurring on any particular day of interest (e.g. date of toxicity experiment in the receiving water.)

3.1.3 Daily Variation in Concentration and Loading

The ammonia concentration in Main STP effluent tends to increase with time of day between 10:00 a.m. and 5:00 p.m. (Figure 3.5). However, there is a great deal of scatter in this relationship, due partly to variation in the timing of the daily cycle from day-to-day, and due also to amplitude variation between days. Amplitude variation between days can be large relative to within-day variation. For example, ammonia varied from 4 to 9 mg/L over the course of the day on 11 September 1986, and from 25 to 30 mg/L on 07





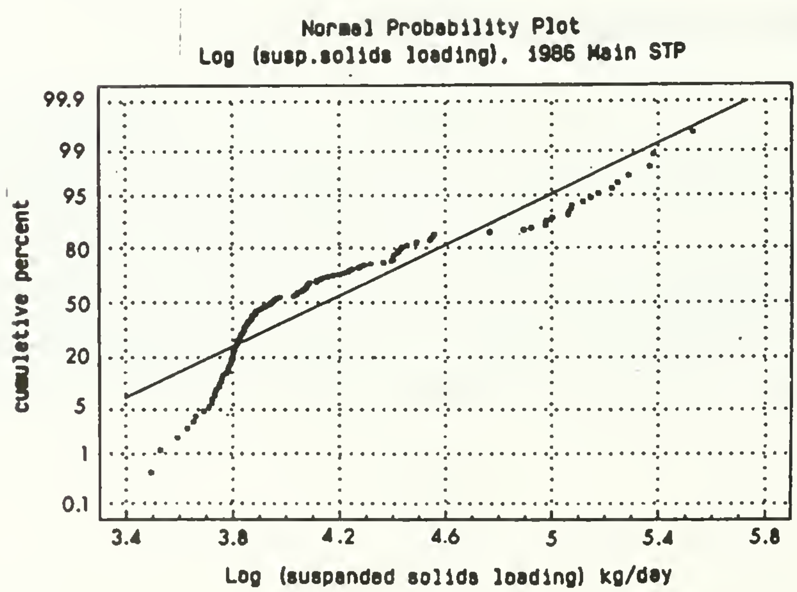
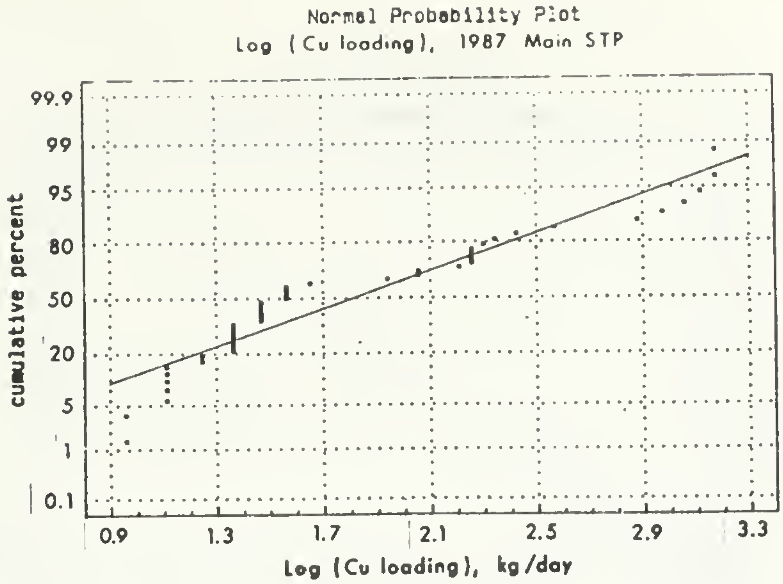
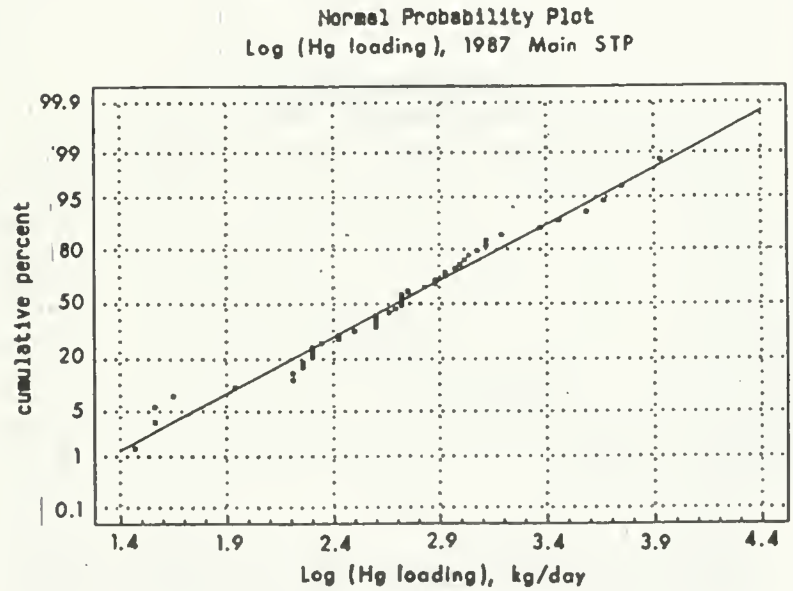


FIGURE 3.2 Probability distributions of loadings. Toronto Main STP, 1986





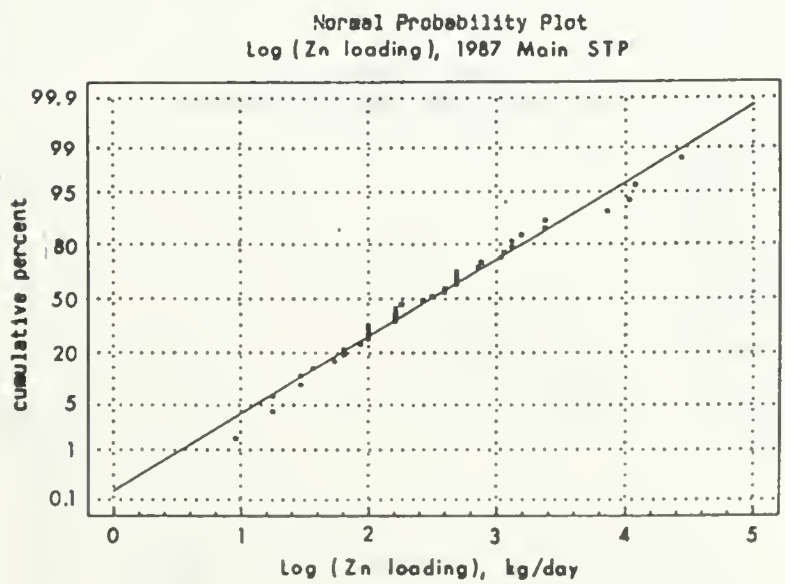
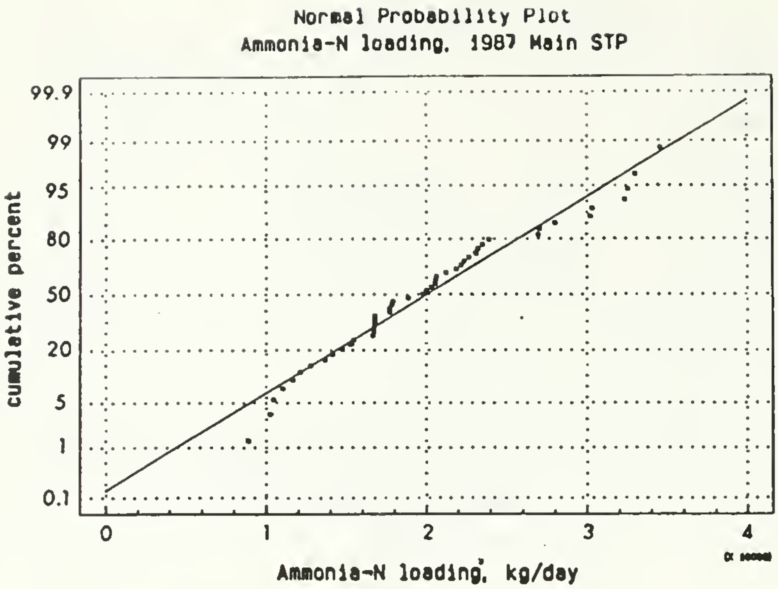
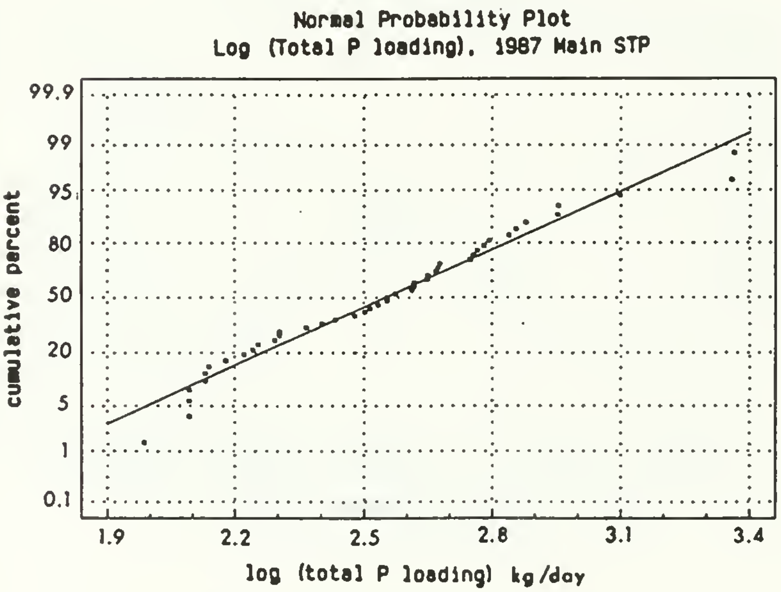


FIGURE 3.4 Probability distribution of metal loadings
Toronto Main STP, 1987





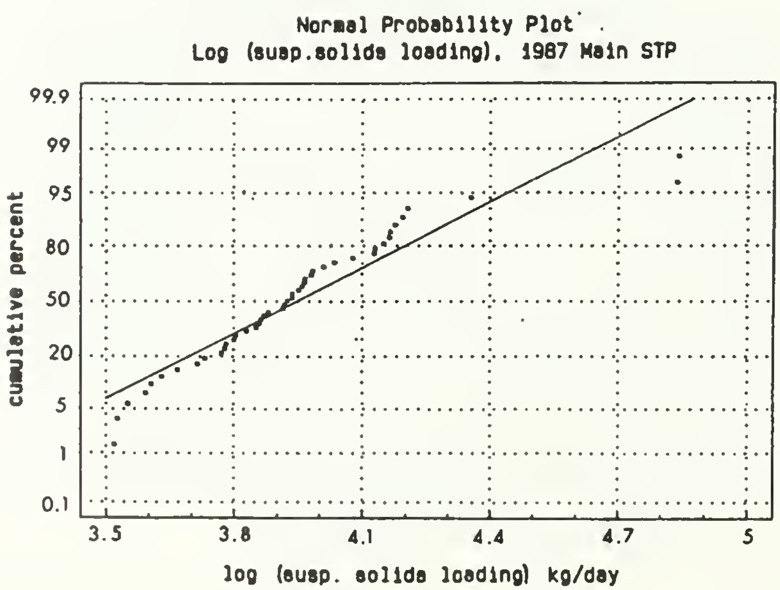


FIGURE 3.3 Probability distributions of loadings, Toronto Main STP, 1987

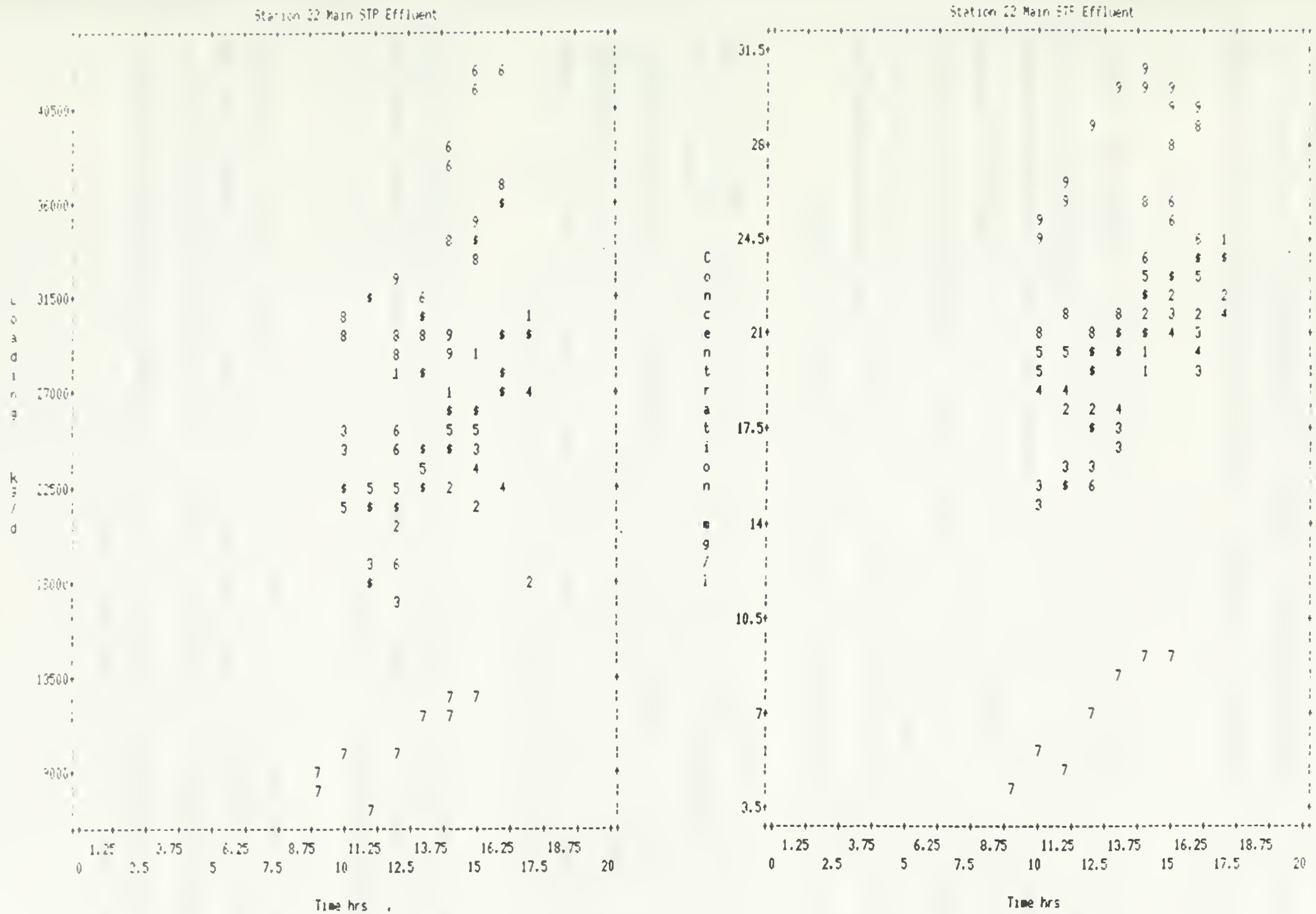


FIGURE 3.5: EFFLUENT TOTAL AMMONIA CONCENTRATION AND LOADING WITH TIME OF SAMPLING IN MAIN STP 1986
(plot symbols indicate date of sample)

1.	12 August	4.	08 September	7.	11 September
2.	13 August	5.	09 September	8.	06 November
3.	14 August	6.	10 September	9.	07 November

November 1986. The pattern of variation in TKN closely resembles that for ammonia. The difference in ammonia and organic nitrogen concentrations in the effluent are seasonally related to temperature because the conversion of ammonia to nitrate nitrogen is bacteriological.

Phosphorus shows a different pattern of variation (Figure 3.6). While the extreme concentrations, representing upset conditions, do tend to be more extreme later in the day, most of the samples cluster at the low end of the concentration scale, even late in the day. Sometimes a pattern of mid-afternoon upset followed by recovery is indicated (for example, on 13 August 1986). This reflects the fact that phosphorus concentrations are one of the effluent concentrations specified in the permit. In addition, the within-day variations shown here indicate that grab sampling of the effluent is of only limited usefulness in determining loadings, as the result obtained may be dependent on the time of sampling.

Flow in the Main STP effluent shows no general pattern of variation with time of day (Figure 3.7). Sometimes flow increases over the course of the day (for example, on 10 September 1986, and 13 August 1986). There is also considerable variation between days (e.g. 800 to 1,200 x $10^3 m^3/d$ on 13 August and 1,400 to 2,100 x $10^3 m^3/d$ on 11 September 1986). Stormwater is included in the Main STP effluent; consequently, flow is greater after a rainfall. There were large rainfall events on 10 and 11 September.

Instantaneous loadings were computed over the course of the day using flow data from the Metro Works Department (readings every 15 minutes). These flows (m^3/d) were multiplied by 1986 concentration data from the Main STP study, matched to the nearest 15 minutes.

The ammonia loadings (Figure 3.5) are less consistent in pattern than the ammonia concentrations. Generally, ammonia loadings tend to increase over the course of the day, following the concentration pattern (for example, on 11 September 1986). However, on other days, the loading pattern fluctuates without reflecting the concentration increase over the course of the day (for example, on 13 August 1986).

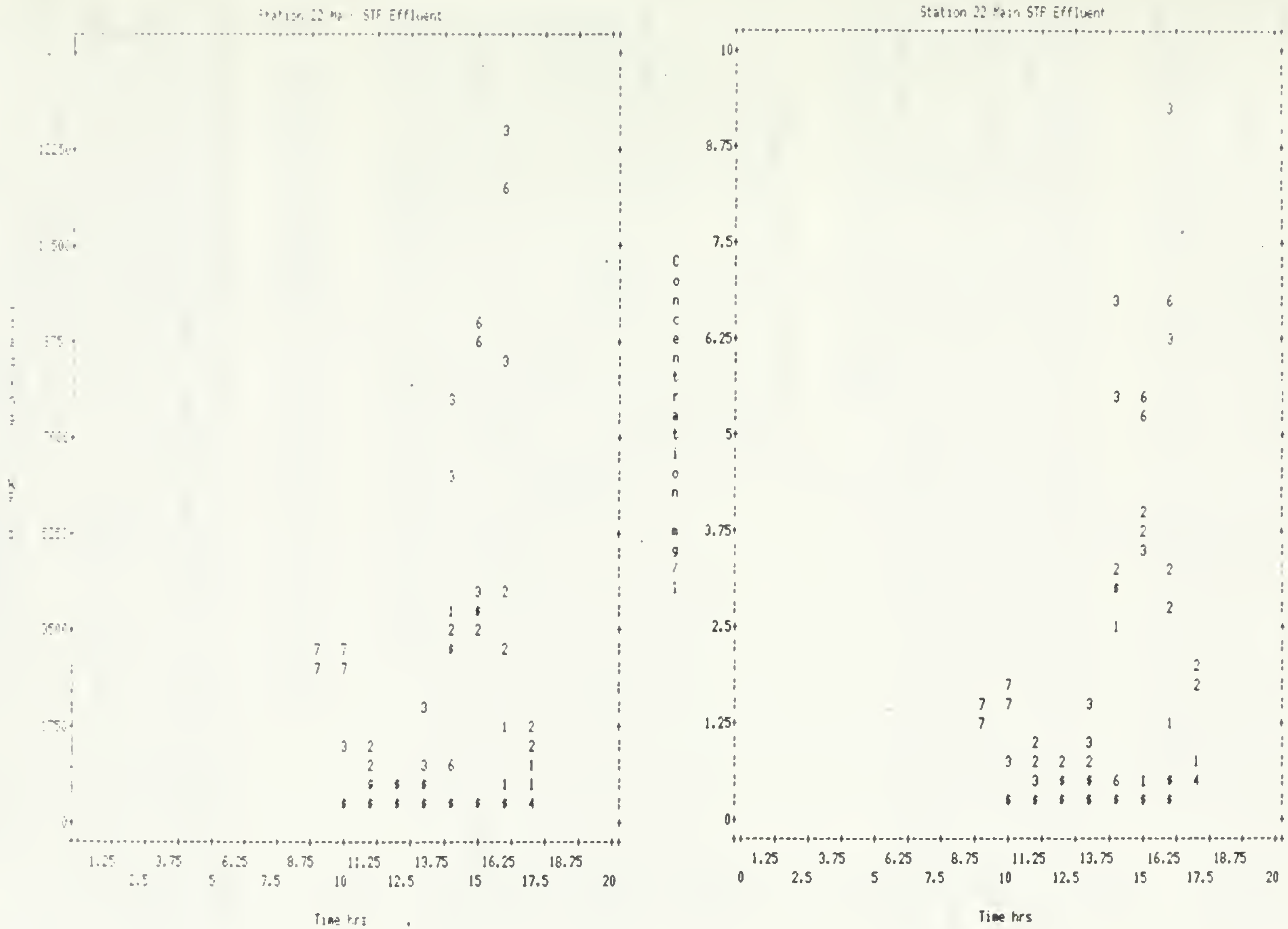


FIGURE 3.6 : EFFLUENT TOTAL PHOSPHORUS CONCENTRATION AND LOADING WITH TIME OF SAMPLING IN MAIN STP 1986
(plot symbols indicate date of sample)

1.	12 August	4.	08 September	7.	11 September
2.	13 August	5.	09 September	8.	06 November
3.	14 August	6.	10 September	9.	07 November

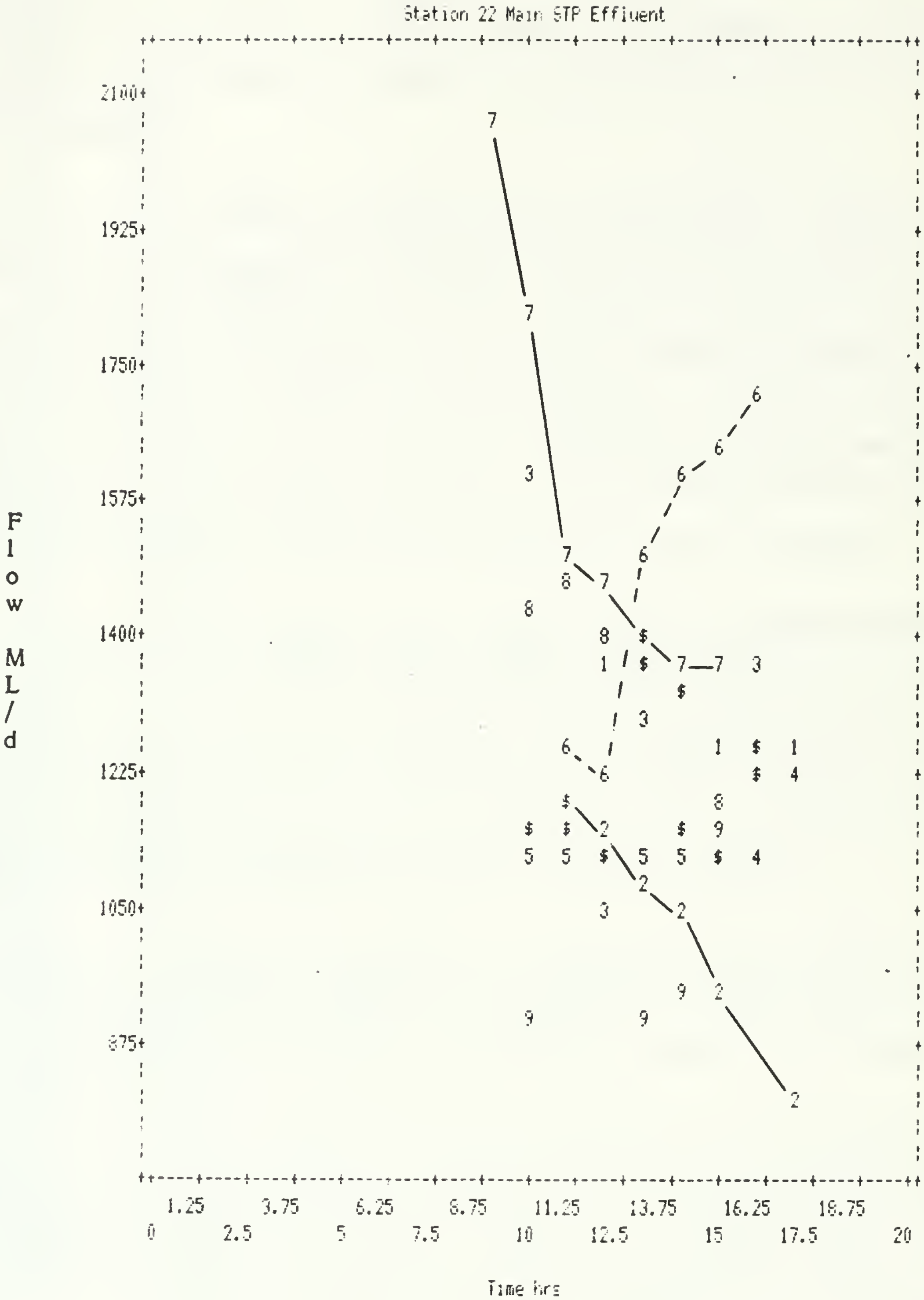


FIGURE 3.7 : EFFLUENT FLOW WITH TIME AT MAIN STP 1986 (plot symbols indicate date of sample)

1. 12 August
2. 13 August
3. 14 August
4. 08 September
5. 09 September
6. 10 September
7. 11 September
8. 06 November
9. 07 November

The loading pattern for phosphorus (Figure 3.6) more closely resembles the concentration pattern. There is a tendency for upset loadings to occur later in the day, although loadings at most times are near the low end of the scale, even late in the day. There is also evidence of recovery following upset (for example, on 13 August 1986). These patterns probably reflect effort to control loadings on the basis of phosphorus.

Daily variation in concentrations of ammonia and phosphorus in the lake near the outfall (Station 1419) do not closely follow either each other, or the corresponding concentrations in the STP. Figure 3.8 illustrates daily variation in both parameters at the outfall in 1986. Figure 3.9 compares the STP and station 1419 concentration patterns for ammonia over a three-day period. This lack of correlation suggests a strong influence of receiving water conditions on outfall concentration.

3.1.4 Interparameter Correlations

Correlations between chemical parameters in the effluent may be used to identify potential surrogate parameters for trace organics or certain metals (e.g., cadmium) that are seldom detectable in the receiving water. Dispersion of the surrogate can be used to infer the dispersion of the trace contaminant. However, the dispersion properties of the surrogate in receiving water should be shown to resemble those of the trace contaminant. This can be tested if the trace contaminant is sometimes detected in receiving water over a meaningful concentration range. Receiving water concentrations above the detection limit can then be checked for correlation with the surrogate.

(a) Parameters Measured at Conventional Detection Levels

Interparameter correlations within the STP effluent are summarized in Table 3.12. Only measurements above the detection limit contribute to these correlation coefficients. The large positive coefficients for suspended solids with all metals suggest that suspended solids may be a useful surrogate for metals. The largest coefficients are for the metals of greatest concern with respect to potential toxicity (Cd, Cr, Cu, Hg, Pb, Zn). Total phosphorus is almost as good, and in fact, superior as a surrogate for nickel. DOC is the best predictor for nickel and Pb, though Pb sample sizes were small.

TABLE 3.12: INTERPARAMETER CORRELATIONS IN MAIN STP, EFFLUENT 1987

	Cadmium	Chromium	Copper	Iron	Mercury	Manganese	Nickel	Lead	Zinc	α-BHC	β-BHC	g-BHC	α-Chlordane	γ-Chlordane	Endosulphan DMDT	Endrin	Sulphate
Conductivity (umhos/cm)	-0.7655* (12)	-0.0972 (47)	-0.2599 (43)	-0.1144 (50)	-0.1400 (47)	0.3198 (47)	0.1915 (47)	-0.0266 (10)	-0.1554 (44)	0.5406* (12)	0.2786 (4)	-0.1265 (21)	0.5463 (5)	0.4483 (7)	-0.8859 (5)	0.5835 (3)	-0.3969 (5)
DOC (mg/L)	-0.2239 (10)	0.5497* (45)	0.1001 (38)	0.5208* (45)	0.6338* (45)	0.3107* (45)	0.5711* (45)	0.9932* (8)	0.4823* (39)	0.1836 (11)	- (1)	0.0044 (18)	-0.3309 (5)	-0.0741 (6)	-0.8193 (3)	0.2508 (3)	-0.9865 (4)
pH	-0.3856 (11)	-0.0106 (46)	0.0417 (39)	0.0587 (46)	0.0117 (46)	0.3593 (46)	-0.2311 (46)	-0.2695 (9)	-0.0892 (40)	0.2110 (11)	- (1)	0.2073 (18)	0.2583 (5)	-0.0161 (6)	0.9577 (3)	-0.9573 (3)	0.2337 (4)
Total Solids (mg/L)	-0.5421 (12)	-0.0647 (46)	-0.1838 (43)	-0.0407 (49)	-0.0696 (46)	0.4607 (46)	0.0386 (46)	0.4265 (10)	-0.0821 (43)	0.5447* (12)	0.8174 (4)	0.2298 (21)	0.6365 (5)	0.6419 (7)	-0.0993 (5)	0.0417 (3)	-0.4578 (5)
Suspended Solids (mg/L)	0.8106* (12)	0.9718* (46)	0.9670* (43)	0.9929* (49)	0.9910* (46)	0.6111* (46)	0.2242* (46)	0.9821* (10)	0.9586* (43)	-0.1101 (12)	-0.3226 (4)	-0.2251 (21)	-0.3418 (5)	-0.1027 (7)	0.8239 (5)	0.9953 (3)	-0.3487 (5)
Ammonia (mg/L)	-0.4799 (12)	0.1136 (47)	-0.0036 (43)	0.0177 (50)	0.0614 (47)	-0.1509 (47)	0.4744* (47)	0.1014 (10)	0.0876 (44)	0.0377 (12)	-0.4875 (4)	-0.2648 (21)	-0.2696 (5)	-0.2639 (7)	-0.2021 (5)	-0.3328 (3)	-0.8418 (5)
Phosphorus (mg/L)	0.7363* (12)	0.8857* (47)	0.8734* (44)	0.8975* (50)	0.9188* (47)	0.5069* (47)	0.3202* (47)	0.8553* (10)	0.8888* (44)	-0.1161 (12)	-0.3283 (4)	-0.2436 (21)	-0.3524 (5)	-0.1112 (7)	0.7976 (5)	0.9983 (3)	-0.3981 (5)

(n) indicates number of samples with paired measurements above detection limits contributing to the correlation coefficient.
* indicates statistical significance based on one-tailed test ($p < 0.01$).

Note: With log transformation prior to computation, coefficients change slightly and a few marginally significant coefficients become insignificant at the stated probability, while a few insignificant coefficients become significant. The superiority of suspended solids and phosphorus as metal surrogates remains unchanged.

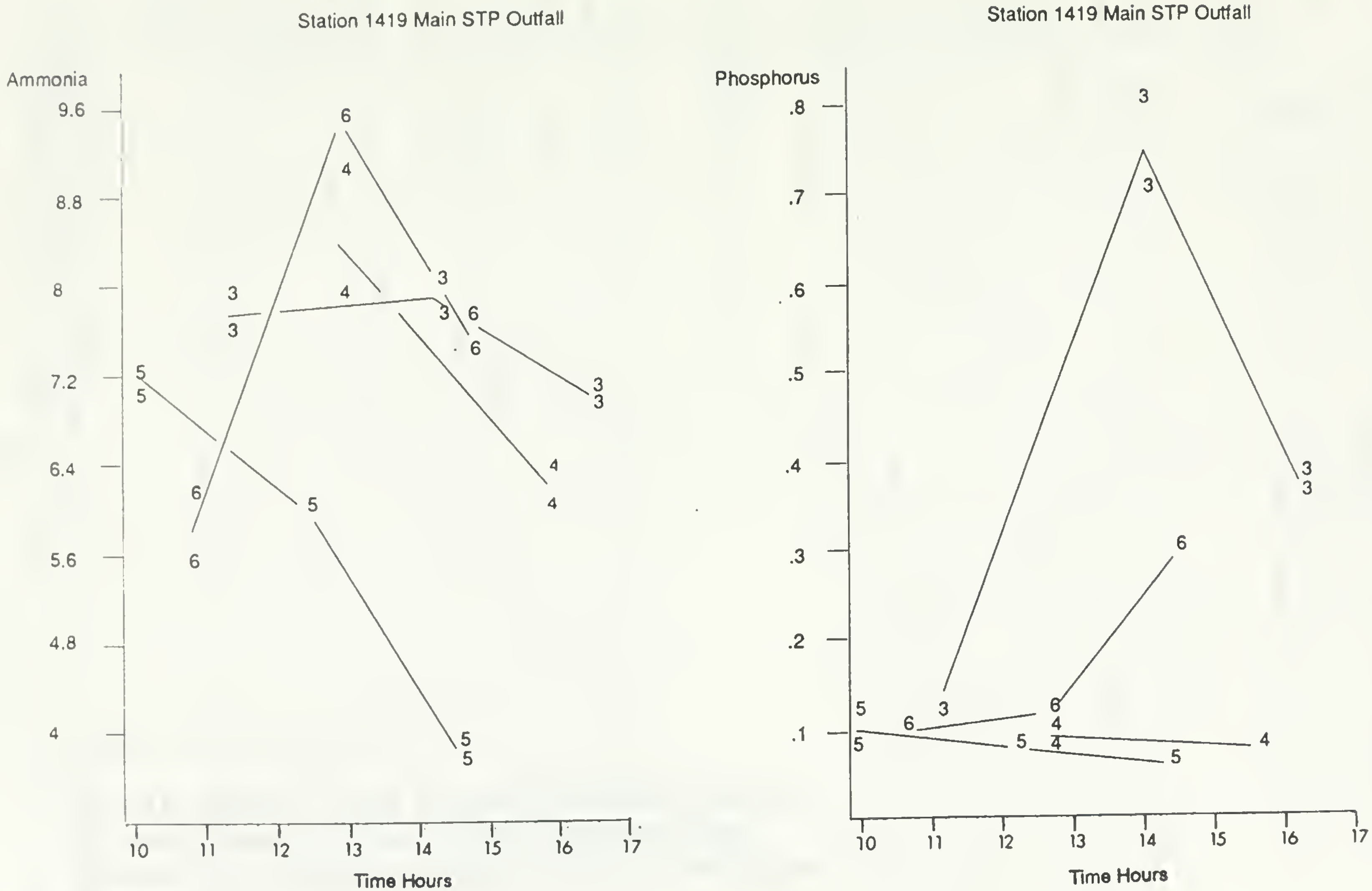
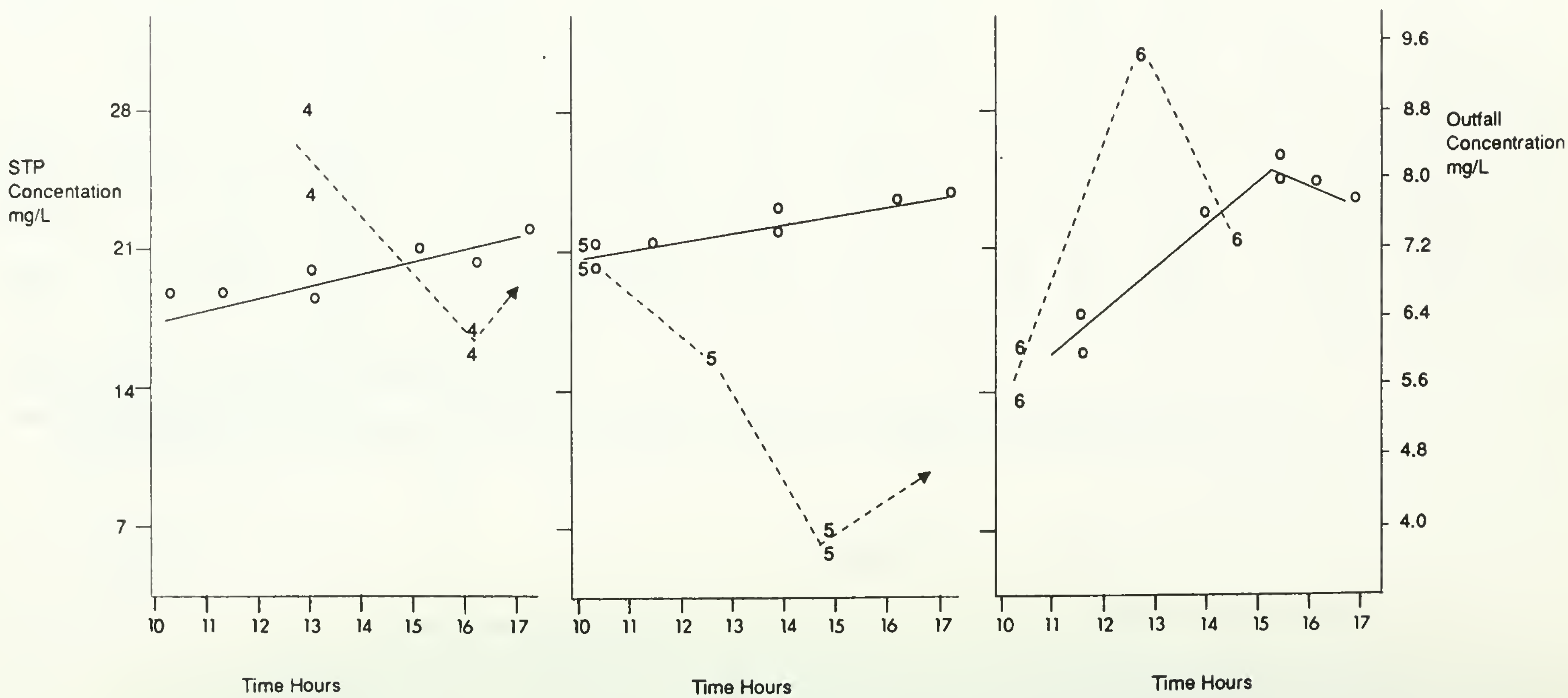


FIGURE 3.8:
Total Ammonia and Phosphorus Concentration With Time of Sampling at Main STP Outfall in 1986 (Plot Symbols Indicate Date of Sample.)
3= 14 August; 4= 08 September; 5= 09 September; 6= 10 September.

FIGURE 3.9:
Relationship of Main STP and Outfall Concentration of Total Ammonia Over a 3-Day Period in 1986.
0 = STP Effluent; 4,5&6 = Outfall, September 8,9,10

Station 1419 Main STP Outfall - - - - -
Main STP ————



The only organic parameter measured above detection limits with sufficient frequency to compute a meaningful correlation to conventional parameters was lindane (γ-BHC). No surrogate for lindane was evident from the correlation coefficients. Asignificant correlation ($r = 0.54$) of α-BHC with conductivity and total solids was suggested, although the sample size ($n = 12$) was small.

The Metro Works Department measures a few conventional chemical parameters in daily composite samples of STP effluent. The 1986-1987 data, over periods coincident with the Main STP Study sampling, were used to examine correlations among conventional parameters. Table 3.13 shows these interparameter correlation coefficients. The correlations between ammonia and TKN ($r = 0.88$) and total phosphorus and suspended solids ($r = 0.85$) are significant ($p<0.05$). The first coefficient reflects the fact that TKN constitutes organic N+ ammonia and, in sewage, is approximately 90% ammonia. The second coefficient explains the similarity of surrogate relationships for phosphorus and suspended solids in Main STP effluent (Table 3.12).

b) Ultra-trace Organic Parameters

The improved detection limits obtained using the 16-L STP samples (Section 2.0; Eli-Eco Laboratories, 1988) permitted an improved search for surrogates of toxic organics which might be especially useful in modelling of the toxics. A subset file containing data for only those dates in 1987 for which ultra-trace samples were collected was prepared, and the following were selected as potential surrogate parameters: ammonia-N, total Kjeldahl N, nitrate + nitrite-N, total P, pH, conductivity, chemical oxygen demand, dissolved organic carbon, total filtered solids and suspended solids. Computer files containing paired observations of conventional and ultra-trace organic data were prepared, and normal distribution plots were prepared using STATGRAPHICS in order to determine the best transformation for approaching normal distribution. In most cases, logarithmic transformation was used. Correlations were then computed using the SPSSPC statistical package.

Initial attempts at correlation revealed many significant negative correlations, and scatterplots revealed that several outlier points were influencing the correlations. Examinations

TABLE 3.13: CORRELATIONS AMONG CONVENTIONAL CHEMICAL PARAMETERS IN MAIN STP EFFLUENT, 1987 (Metro Works Data)

Chemical Parameter	Total Ammonia	TKN	Total Suspended Solids	Total Phosphorus	pH	Fecal Coliforms
Total Residual Chlorine	-0.2894* (57)	-0.2954* (57)	0.0650 (104)	0.0411 (105)	0.1377 (107)	-0.5466* (46)
Total Ammonia		0.8836* (57)	-0.1141 (56)	-0.1667 (56)	0.0388 (57)	0.2224 (31)
TKN			0.1678 (56)	0.1386 (56)	-0.1618 (57)	0.2853 (31)
Total Suspended Solids				0.8478* (103)	-0.1708* (104)	-0.0158 (45)
Total Phosphorus					-0.2168* (104)	0.1294 (45)
pH						-0.2047 (46)
Fecal Coliforms						

(n) indicates number of samples with paired measurements above detection limits contributing to the correlation coefficient.

* indicates statistical significance based on one-tailed test ($p<0.05$).

TABLE 3.14: CORRELATIONS BETWEEN CONVENTIONAL AND ULTRA-TRACE ORGANIC PARAMETERS, MAIN STP, 1987

Correlations:	DCB13	DCB14	DCB12	TCB135	TCB124	TCB123	TECB1235	TECB1245	TECB1234
NNHTFR	.5741	-.2510	.1717	-.1932	.5048	.7342*	.8666**	.8369**	.6837*
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.065	P=.457	P=.614	P=.569	P=.113	P=.010	P=.001	P=.001	P=.020
NNOTFR	-.7351*	-.0730	-.6074*	-.2746	.1980	.1207	.2441	.1654	.0936
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.010	P=.831	P=.047	P=.414	P=.559	P=.724	P=.469	P=.627	P=.784
NNTKUR	.6072*	-.3038	.3232	-.3018	.5523	.7111*	.8395**	.8037**	.7418**
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.048	P=.364	P=.332	P=.367	P=.078	P=.014	P=.001	P=.003	P=.009
PPUT	.5180	.1515	.9800**	-.6008	.5283	.2945	.2305	.2691	.5881
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.103	P=.657	P=.000	P=.051	P=.095	P=.379	P=.495	P=.424	P=.057
PH	-.1114	.2040	-.7322*	.9085**	-.7429**	-.1935	-.3011	-.2570	-.6013
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.744	P=.547	P=.010	P=.000	P=.009	P=.569	P=.368	P=.446	P=.050
COD	.5604	-.3794	.8267**	-.6314	.7133*	.6292	.7189*	.6763*	.8606**
	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)
	P=.117	P=.314	P=.006	P=.068	P=.031	P=.069	P=.029	P=.045	P=.003
COND25	.8777**	-.0089	.6362*	.0923	.1733	.4002	.3136	.3658	.3827
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.000	P=.979	P=.035	P=.787	P=.610	P=.223	P=.348	P=.269	P=.245
DOC	.9305**	.1458	.7104*	-.0560	.3121	.5484	.4728	.5441	.5313
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.000	P=.669	P=.014	P=.870	P=.350	P=.081	P=.142	P=.084	P=.093
RSF	.7169*	.2400	.2582	.5920	-.2992	.2171	.0091	.1049	-.0240
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.013	P=.477	P=.443	P=.055	P=.371	P=.521	P=.979	P=.759	P=.944
RSP	.4426	.3116	.8966**	-.5098	.5066	.4008	.2509	.3114	.5877
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)
	P=.173	P=.351	P=.000	P=.109	P=.112	P=.222	P=.457	P=.351	P=.057

Note: First number is correlation coefficient
Bracketed number is no. of observations
P = probability of random correlation.

Organic parameters are as follows:

DCB13 = 1,3-dichlorobenzene
DCB14 = 1,4-dichlorobenzene
DCB12 = 1,2-dichlorobenzene
TCB135 = 1,3,5-trichlorobenzene
TCB124 = 1,2,4-trichlorobenzene
TCB123 = 1,2,3-trichlorobenzene

TECB1235 = 1,2,3,5-tetrachlorobenzene
TECB1245 = 1,2,4,5-tetrachlorobenzene
TECB1234 = 1,2,3,4-tetrachlorobenzene

* - P<0.05
** - P<0.01

TABLE 3.14: (cont'd)

QCB	HCB	HCE	α-BHC	γ-BHC	GCHLOR	ACHLOR	PCB
-.7070* (11) P=.015	.5999 (11) P=.051	-.4540 (11) P=.161	-.1457 (11) P=.669	-.5662 (11) P=.069	-.0100 (11) P=.977	.4275 (11) P=.190	.3776 (11) P=.252
.1750 (11) P=.607	-.5910 (11) P=.056	-.5071 (11) P=.111	-.6545* (11) P=.029	-.3619 (11) P=.274	-.1525 (11) P=.654	-.8957** (11) P=.000	.1226 (11) P=.719
-.8112** (11) P=.002	.7193** (11) P=.013	-.4505 (11) P=.164	-.0256 (11) P=.940	-.4632 (11) P=.151	.1589 (11) P=.641	.5073 (11) P=.111	.4300 (11) P=.187
-.7439** (11) P=.009	.8453** (11) P=.001	.0627 (11) P=.855	.0996 (11) P=.771	-.0408 (11) P=.905	.8190** (11) P=.002	.6211* (11) P=.041	.4203 (11) P=.198
.7692** (11) P=.006	-.6095** (11) P=.047	.4446 (11) P=.171	.1437 (11) P=.673	.0681 (11) P=.842	-.9105** (11) P=.000	-.2052 (11) P=.545	-.2695 (11) P=.423
-.9776** (9) P=.000	.9505** (9) P=.000	-.5114 (9) P=.159	.0556 (9) P=.887	-.2664 (9) P=.488	.6147 (9) P=.078	.5542 (9) P=.122	.5541 (9) P=.122
-.5677 (11) P=.068	.8489** (11) P=.001	.2206 (11) P=.515	.4838 (11) P=.132	-.0025 (11) P=.994	.2081 (11) P=.539	.9524** (11) P=.000	.2240 (11) P=.508
-.6664* (11) P=.025	.8932** (11) P=.000	.1729 (11) P=.611	.1902 (11) P=.575	-.2919 (11) P=.384	.2191 (11) P=.517	.9258** (11) P=.000	.3435 (11) P=.301
-.0353 (11) P=.918	-.4286 (11) P=.188	-.6084* (11) P=.047	-.5537 (11) P=.077	.0823 (11) P=.810	-.2560 (11) P=.447	-.7655** (11) P=.006	.0823 (11) P=.810
-.6475* (11) P=.031	.7528** (11) P=.007	.1859 (11) P=.584	-.0359 (11) P=.917	-.1331 (11) P=.696	.7328* (11) P=.010	.5387 (11) P=.087	.4863 (11) P=.129

Note: First number is correlation coefficient
Bracketed number is no. of observations
P = probability of random correlation

Organic parameters are as follows:

QCB = pentachlorobenzene
HCB = hexachlorobenzene
HCE = hexachloroethane
ABHC = α-BHC
GBHC = γ-BHC (lindane)
GCHLOR = γ-chlordane
ACHLOR = α-chlordane
PCB = Total PCBs

of the raw data for conventional parameters in the Main STP effluent indicated excessively high (>100 mg/L) suspended solids concentrations in the samples collected on June 2 and October 5. These samples also had abnormally high total phosphorus and COD concentrations. These two dates were excluded from the calculations; in addition the data for COD only on July 28 (trace to non-detect at all four STPs) were excluded and the correlations rerun.

Interparameter correlations thus obtained are summarized in Table 3.14. The largest number of significant positive correlations ($P<0.05$) are found for ammonia, total Kjeldahl N and chemical oxygen demand. No more than three toxic parameters are correlated with any conventional parameters at the $P<0.01$ level. The low number of correlations is not surprising given the small number ($N = 11$) of paired observations; this number is even somewhat of an artifact as the single ultra-trace results were duplicated to pair with the replicate conventional results, and in fact only eight ultra-trace samples were actually used in the correlations.

In contrast to metals, where suspended solids was found to be a surrogate for most parameters, no one parameter acts as a surrogate for all trace organics; in addition, no significant surrogate was found for several parameters (most notably PCBs). Besides the small number of samples available for correlation, the range of values for some parameters (e.g. conductivity) was limited. Short-term variability of effluent concentrations may be great, in particular the amount of suspended material, as was observed on June 2 and October 5. This may have a strong impact on organic concentrations, as the conventional and trace organic samples were not necessarily collected at exactly the same time and it is known that hydrophobic organic compounds may sorb strongly to particulate matter.

In summary, the data collected from the Main STP were not adequate to establish correlations between conventional and ultra-trace compounds to a high level of confidence. It is recommended that a larger number of samples be obtained (including daily replicates for ultra-trace organic analyses); furthermore, conventional and ultra-trace samples should be collected together and extremes in suspended solids concentrations be avoided where possible as the heterogeneous nature of such samples renders it difficult to establish the representative nature of such samples.

3.2 Lake Ontario, Main STP Area

Water quality data were collected at stations in the vicinity of the Main STP during 1986 and 1987 (Figures 1.1 and 1.2) in support of the overall Main STP MISA water quality component described in this report, as well as the various toxicity tests described in other component reports. This included some mid-depth and bottom samples as well as surface samples; additional details of the sampling program are given in Section 2.0.

The water quality summary for each station includes the mean, median, standard deviation, minimum and maximum concentrations of each measured chemical parameter. The maximum likelihood (MLE) method (El-Sharaawi, 1989; El-Sharaawi and Dolan, 1989) was used for parameters such as metals and organics, which are frequently below the analytical detection limit. Summaries for these parameters include the upper and lower confidence limits for the mean, as well as the frequency of samples below the detection limit, or above the provincial water quality objectives for protection of aquatic life (PWQOs). For residual chlorine, which decays rapidly in the lake, concentrations below the detection limit were considered to be zero. A comparison of several methods of handling "non-detect" results is given in Appendix 4. A separate summary is presented for surface and bottom samples in Appendix 1 (toxicity test periods) and Appendix 2 (annual statistics).

In 1986, the water depth of "surface" samples varied between 0.1 and 1.0 m in an apparently random fashion. Profiling results (Section 3.2.5) indicates that significant depth variations do occur, with highest concentrations at the surface. However, it was felt that horizontal as well as short-term temporal variability was at least as great as depth variability in the top meter; consequently, surface data within this depth interval were pooled before calculation of statistical summaries.

3.2.1 Water Quality During Toxicity Tests

Toxicity tests were performed in situ by the MOE at stations near the Main STP outfall. Rainbow trout were placed in fish cages to detect any acute mortality on 12-14 August, 08-10 September and 04-07 November 1986; and on 15-19 June and 06-10 July 1987 (Flood, 1990). In addition, clams were placed in cages to detect any chronic mortality or bioaccumulation on 16 June - 08 July and 13 October - 05 November 1987 (Aquatic Sciences, 1987). Water quality in the vicinity of Main STP during these periods is summarized briefly in this section. Detailed summary statistics for each station are included in Appendix 1. Results of these toxicity tests are reported in other Toronto MISA component reports (Flood, 1990; Hayton, 1990, Neville, 1990, etc.)

During toxicity test periods, each sample was considered a separate unit of observation, even though some samples were field replicates. This has the effect of biasing mean concentrations toward dates and times of replication. However, these studies did not span long time periods.

The chemical parameters which exceed PWQOs (MOE, 1984) near the Main STP outfall include ammonia (presented as a total concentration, but used as unionized ammonia in exceedence evaluation), phosphorus, chlorine, iron, copper, zinc and cadmium. Ammonia and phosphorus were usually in exceedence at the outfall (Station 1419) and often in exceedence near the outfall (Stations 1431 to 1434). The PWQO for both phosphorus and unionized ammonia is 0.02 mg/L. These nutrient concentrations were consistently greater near the surface than near the bottom, and tended to decline from August through November (Table 3.15).

Total residual chlorine, as measured in the field, was consistently detected at a detection limit of 6 μg/L at the Main STP outfall, and was frequently detected within 500 m of the outfall. This parameter was always in exceedence of its PWQO (2 μg/L) when detected. However, a single measurement at a control station (20 μg/L at Station 2029 in September 1986) also exceeded this objective. When residual chlorine was not detected, the concen-

TABLE 3.15: WATER QUALITY MEANS AT STATION 1419 DURING TOXICITY TEST PERIODS (see Appendix 1 for complete statistical summary)

Parameter[1]	Test Period 12-14 Aug 86	08-10 Sept 86	04-07 Nov 86	15-19 June 87	16 June-08 July 87
Surface (0-1 m depth)					
Sampling Time (hrs)	14.2	12.9	13.6	11.0	11.2
Temperature (°C)	14.6	13.1	11.6	12.9	13.0
Conductivity (μmho/cm)	-	547	502	-	-
pH	7.88	-	7.84	7.2	7.1
Residual Chlorine(μg/L)	551	1028	-	513	496
Field Ammonia	7.30	6.75	5.17	5.46	4.91
Lab Ammonia	6.79	6.17	4.55	-	-
Phosphorus	0.296	0.116	0.078	0.14	0.10
Iron	0.313	0.143	0.434	0.284	0.277
Copper	0.007	0.004	0.004	0.005	0.005
Zinc	0.017	0.012	0.008	0.006	0.006
Turbidity (FTU)	5.94	2.5	9.5	3.31	3.23
Chlorophyll a (μg/L)	-	1.5	2.9	-	-
Bottom or Depth of Turbidity Max. (4-6 m)					
Sampling Time (hrs)	14.2	12.9	13.6	10.8	11.0
Temperature (°C)	11.2	9.2	8.8	8.5	8.9
Conductivity (μmho/cm)	-	367	322	-	-
pH	7.96	-	8.22	7.8	7.8
Residual Chlorine(μg/L)	377	137	-	0	0
Field Ammonia	4.40	1.76	0.91	0.29	0.36
Lab Ammonia	4.16	1.42	0.59	-	-
Phosphorus	0.154	0.069	0.046	0.42	0.04
Iron	0.208	0.080	0.581	0.182	0.191
Copper	0.006	0.002	0.003	0.003	0.001
Zinc	0.016	0.003	0.006	0.004	0.002
Turbidity (FTU)	4.16	1.8	17.2	2.60	2.60
Chlorophyll a (μg/L)	-	1.5	3.0	-	-

[1] Units are mg/L unless otherwise indicated.

tration was considered to be zero. It should also be noted that the total residual chlorine result, when measured in the presence of ammonia (as is the case here) includes mono- and di-chloramines as well as free chlorine.

Heavy metals (iron, copper, zinc and cadmium) exceeded PWQOs occasionally at Station 1419 during toxicity test periods. Cadmium was usually either non-detectable or in exceedence, since its PWQO (0.2 μg/L) was equal to the detection limit. The PWQOs for iron, copper and zinc are 0.3, 0.005 and 0.03 mg/L, respectively. Heavy metals were not present in receiving water at levels likely to have caused acute toxicity (MOE, 1990).

The chemical parameters most likely to be responsible for toxic responses near the Main STP outfall were residual chlorine and/or ammonia. Acute toxicity to rainbow trout may be expected at approximately 50 to 200 μg/L free chlorine (U.S. EPA, 1984) or 10 mg/L total ammonia. Ammonia toxicity depends on pH and temperature which dictate the fraction of ammonia in unionized form (Emerson et al. 1975; MOE, 1984):

$$\text{Fraction Unionized Ammonia} = \frac{1}{1 + 10^{(pKa-pH)}}$$

$$\text{where: } pKa = 0.09 + \frac{2{,}730}{273 + \text{Temperature } (^\circ C)}$$

Residual chlorine concentrations appear to be closer to acute toxic levels in general, and often considerably in excess of acute toxic thresholds for fish.

3.2.2 Annual Summaries, Concentration Isopleths and Dilution Factors

The annual water quality summaries for stations in the vicinity of the Main STP in 1986 and

1987 follow the same format as the summaries for toxicity test periods. They include the concentration mean, median, standard deviation, minimum and maximum, and frequen-cies below detection limits or above PWQOs (Appendix 2). However, in this case, N represents the number of sampling days and the daily mean is the unit of observation. This was considered preferable for representation of general spatial/temporal pattern since it prevents bias due to weighting of local means towards dates of greatest replication; however, standard deviations and exceedences may not reflect the full range of diurnal variation in 1986 when several samples per day were sometimes taken. Replication was not performed in 1987, and stations were seldom sampled more than once per day.

Annual station means and standard deviations were plotted on maps of the Main STP area in order to illustrate dilution patterns in the vicinity of the Main STP outfall. Approximate concentration isopleths in 1987 were estimated from plots of concentration vs. distance from source on northeast and southwest transects. The form and extent of the concentration contour in the southeasterly direction is based entirely on speculation, since no sampling was performed in this direction. Rapid dilution in this direction might be expected since currents generally run toward the northeast or southwest (see Section 4.3).

Concentration isopleths were also expressed as dilution isopleths (i.e. 1: x dilution) as follows:

$$X = \frac{\text{Source - Background}}{\text{Concentration - Background}}$$

where: Concentration is estimated from the plot described above.

Effluent concentrations in the STP were used as source concentrations. Background was estimated from the control station means. The value of X increases with dilution. Concentrations can also be expressed as a relative concentration equal to 1/X which decreases with dilution. The X values at some individual stations, based on observed station means, are listed in Table 3.16.

TABLE 3.16: DILUTION FACTORS[1] FOR DIFFERENT CHEMICALS AT SELECTED INDIVIDUAL STATIONS IN 1987

Chemical Parameter[2]	Station Number					
	1419	2877	2909	2878	2910	2209
Field Ammonia:						
0.5 m depth	3.1	32.	32.	14.	45.	80.
6.0 m depth	80.	300.	300.	45.	300.	-
Lab Ammonia	2.9	40.	110.	8.7	19.	110.
Residual Chlorine[3]	3.0	21.	28.	-	-	400.
Phosphorus	5.0	25.	40.	27.	40.	80.
Conductivity	3.0	18.	22.	14.	40.	100.
DOC	3.3	20.	27.	16.	50.	130.
Fecal Coliforms	6.6	470.	700.	27.	50.	700.
Copper	5.4	36.	100.	29.	29.	150.
Zinc	7.1	55.	150.	75.	70.	400.
Iron	4.1	20.	28.	16.	40.	30.
Manganese	3.2	17.	28.	12.	24.	75.

[1] Dilution Factor = (Source-Background) / (Concentration-Background)

[2] Chemical measured at 0.5 m water depth in receiving water, unless otherwise indicated.

[3] Source concentration of free chlorine assumed = 1000 μg/L; other concentrations averaged over period of Main STP chlorination (June-September).

The spatial distributions of ammonia (field and lab measured) and total phosphorus are llustrated in Figure 3.10. Concentration isopleths of field-measured ammonia at 0.5 m depth suggest dilution to approximately 0.5 mg/L within about 1 km from the outfall. Using lab-measured ammonia as a source concentration, 1:40 dilution is found near the headland 1.5 km southwest of the outfall. At a 6 m water depth, dilution to 0.1 mg/L is suggested within 1 km of the outfall. Acute toxic levels depend on temperature and pH, but are likely in the 10 mg/L range (MOE, 1990). While Flood (1990) did not find acute lethality to rainbow trout during exposures at times when the effluent was nonchlorinated, Neville (1990) found sublethal effects (growth reduction) at station 1419 in such times.

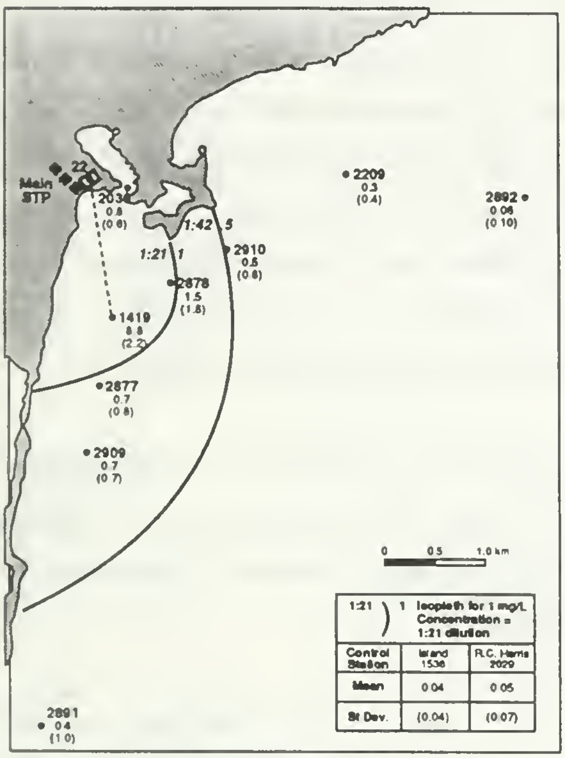
Lab-measured ammonia at 0.5 m depth is diluted to approximately 0.1 mg/L (1: 200 dilution) within 1 km of the outfall. Contours extend slightly toward the northeast in contrast to the field ammonia pattern. Lab measurements suggest slightly more rapid dilution than field measurements, possibly due to high bias in field measurements, or low bias in lake measurements, at low concentrations.

pH is slightly depressed near the Main STP outfall. The mean at Station 1419 is 7.3±0.3 units. A range of 6.5 to 8.5 is considered to be within PWQO. Average pH in Lake Ontario near Toronto is around 8.5. pH is probably more important as a modifier of ammonia toxicity than for any direct toxic effects. As pH decreases, the fraction of unionized ammonia (and the ammonia toxicity) also decreases.

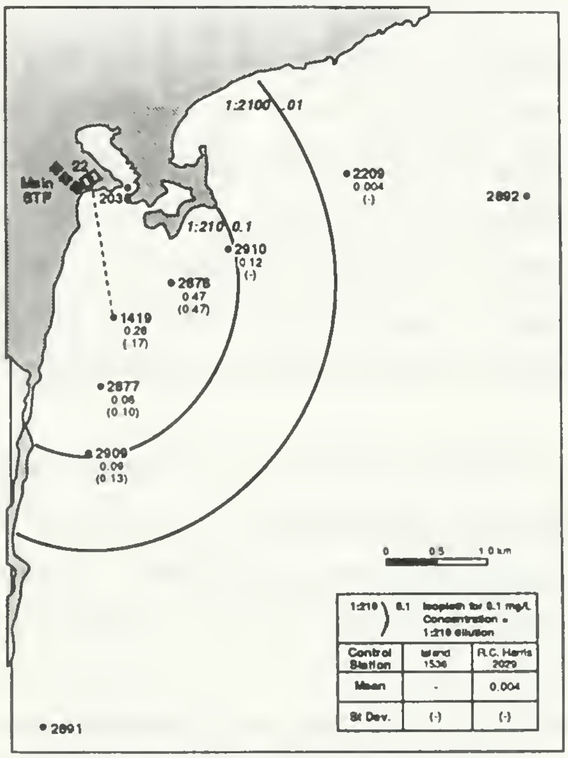
Phosphorus concentration isopleths at 0.5 m depth extend slightly toward the southwest, as for most other chemical parameters. An unusually high mean at Station 2910 was ignored in isopleth calculation. The data suggest dilution to 0.03 mg/L (1:20 dilution) at a distance of 2 to 3 km from the outfall.

Figure 3.10

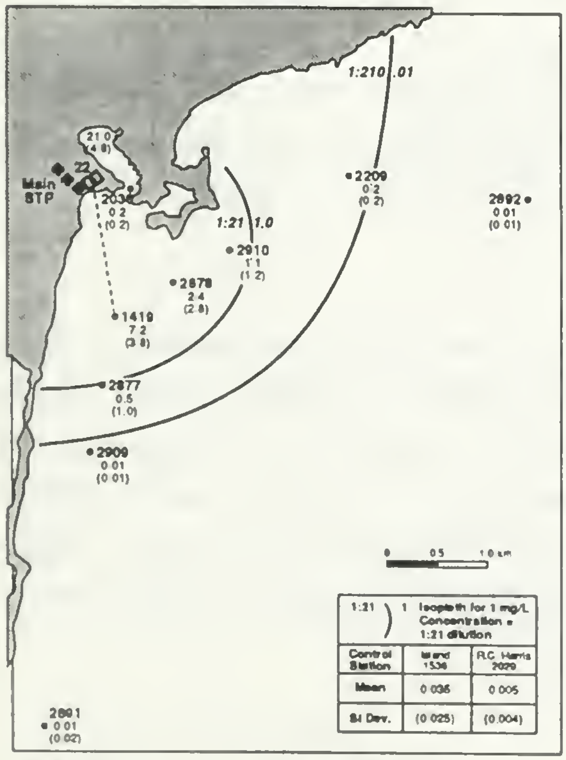
Spatial distribution of ammonia and phosphorus in 1987



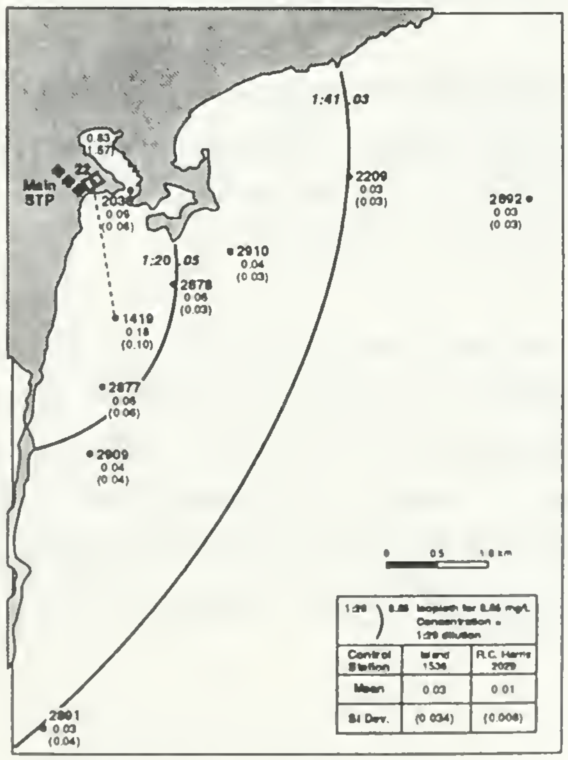
Field Ammonia (mg/L) at 0.5m depth in 1987



Field Ammonia (mg/L) at 6m depth in 1987



Lab Ammonia (mg/L) at 0.5m depth in 1987



Phosphorus (mg/L) at 0.5m depth in 1987

Figure 3.11 shows the spatial distributions of residual chlorine, fecal coliforms, suspended solids and conductivity at 0.5 m depth in 1987. Isopleths of chlorine residual were determined on the assumption of zero free chlorine in when none was detected; however, October and November data were excluded from the calculation since STP chlorination ceases in October. The data suggest chlorine as high as 330 μg/L near the STP outfall, declining to about 40 μg/L 1 km south of the outfall (station 2909). Acute toxic levels for rainbow trout are approximately 80 to 150 μg/L (MOE, 1990); Flood (1990) found acute lethality to rainbow trout when caged at locations within 500 m of the outfall. Acute lethality to fathead minnows was also found with station 1419 water (Neville, 1990).

Fecal coliform isopleths at 0.5 m depth extend slightly to the northeast, as for lab-measured ammonia. Concentrations are expressed as logs; however, dilution factors are computed using geometric means in Figure 3.11. Dilution occurs to approximately ten organisms per 100 mL within 1 to 2 km of the outfall (1:300 dilution).

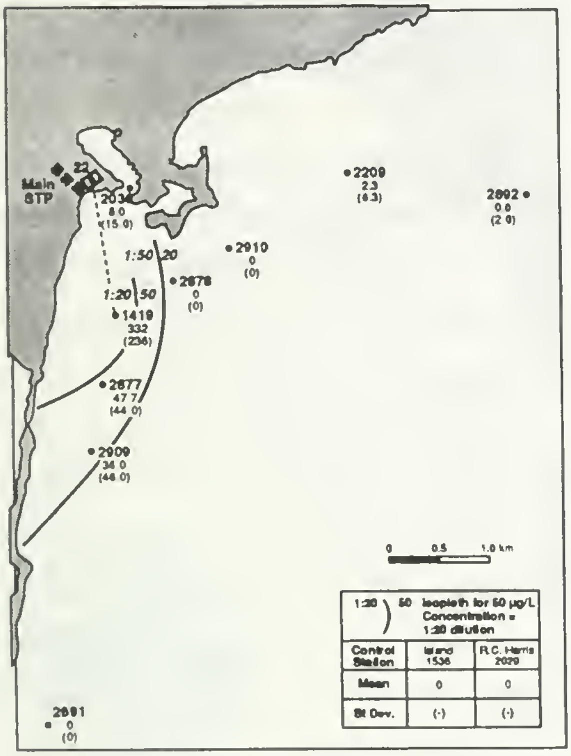
Suspended solids show very symmetric concentration isopleths, with dilution to about 2 mg/L within 1 km of the outfall (a dilution factor of 1:25). This dilution rate is similar to that of other chemical parameters.

Conductivity is diluted essentially to background levels within 1 km of the outfall. As for suspended solids, the dilution contours are quite symmetrical, at least in the vicinity of the STP outfall. The high natural background may obscure current and wind effects further away from the outfall.

A few heavy metals are sufficiently detectable to examine dilution patterns. Average concentrations have been estimated using the maximum likelihood estimator (MLE; Appendix 2 and 4) (Figure 3.12). Copper concentration isopleths at 0.5 m depth suggest that copper is diluted to background levels (0.001 mg/L) within 1 km of the outfall. Zinc is diluted to approximately 0.002 mg/L within 1 km of the outfall (1:100 dilution), slightly above the 0.001 mg/L background. Iron is diluted to approximately 0.06 mg/L within

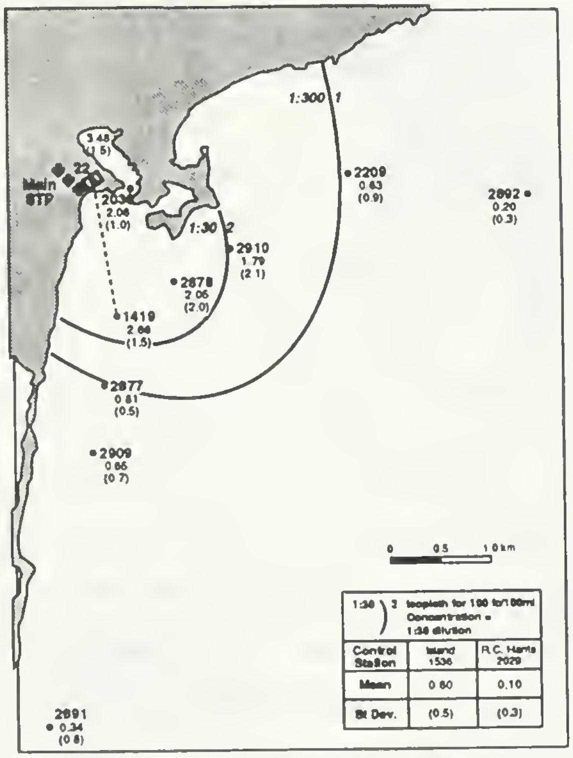
Figure 3.11

Spatial distribution of several conventionals in 1987



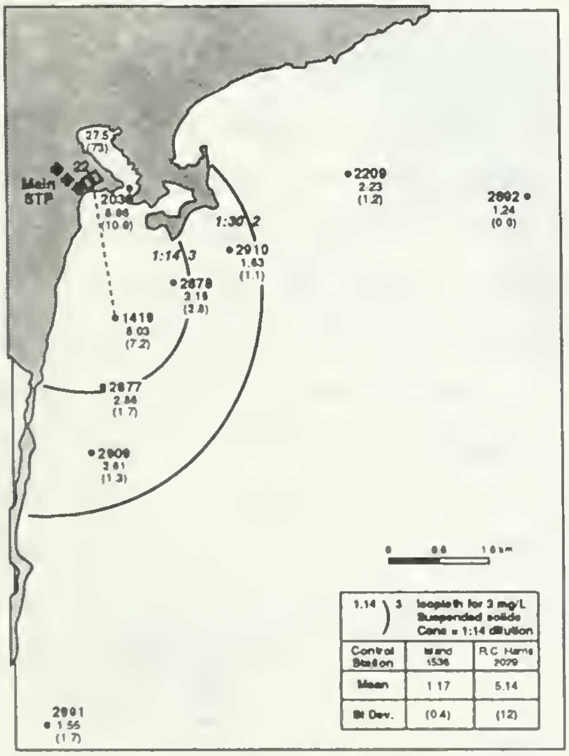
1:20) 50 Isopleth for 50 µg/L Concentration = 1:20 dilution		
Control Station	Island 1536	R.C. Harris 2029
Mean	0	0
St Dev.	(-)	(-)

Chlorine residual (µg/L) at 0.5m depth in 1987



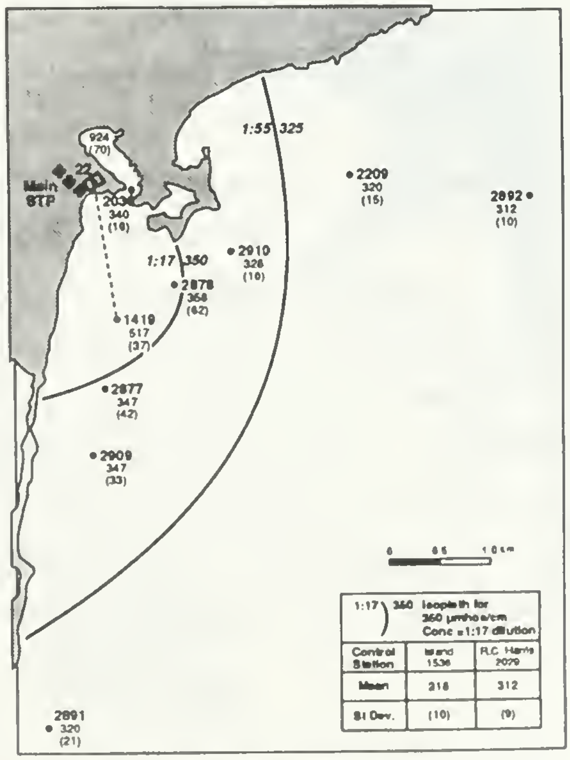
1:30) 2 Isopleth for 100 fc/100ml Concentration = 1:30 dilution		
Control Station	Island 1536	R.C. Harris 2029
Mean	0.60	0.10
St Dev.	(0.5)	(0.3)

Fecal coliforms (log#/100ml) at 0.5m depth in 1987



1.14) 3 Isopleth for 3 mg/L Suspended solids Conc = 1:14 dilution		
Control Station	Island 1536	R.C. Harris 2029
Mean	1.17	5.14
St Dev.	(0.4)	(12)

Suspended solids (mg/L) at 0.5m depth in 1987

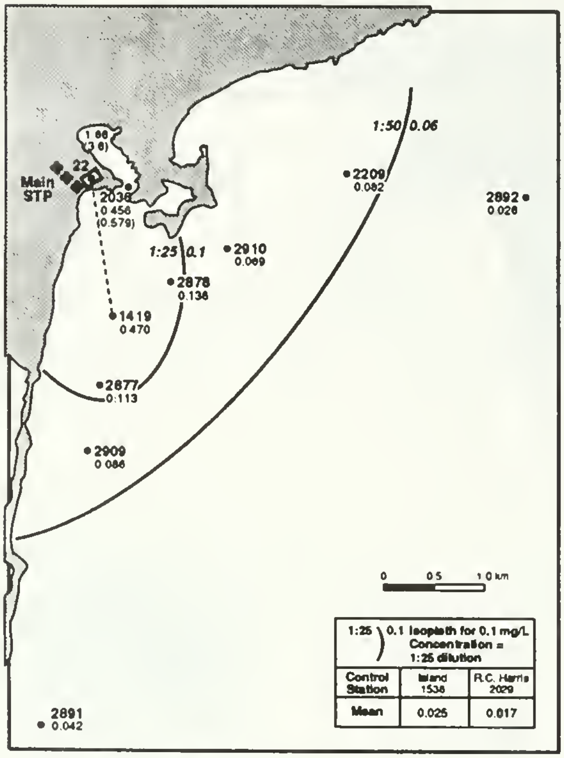


1:17) 350 Isopleth for 350 µmhos/cm Conc = 1:17 dilution		
Control Station	Island 1536	R.C. Harris 2029
Mean	318	312
St Dev.	(10)	(9)

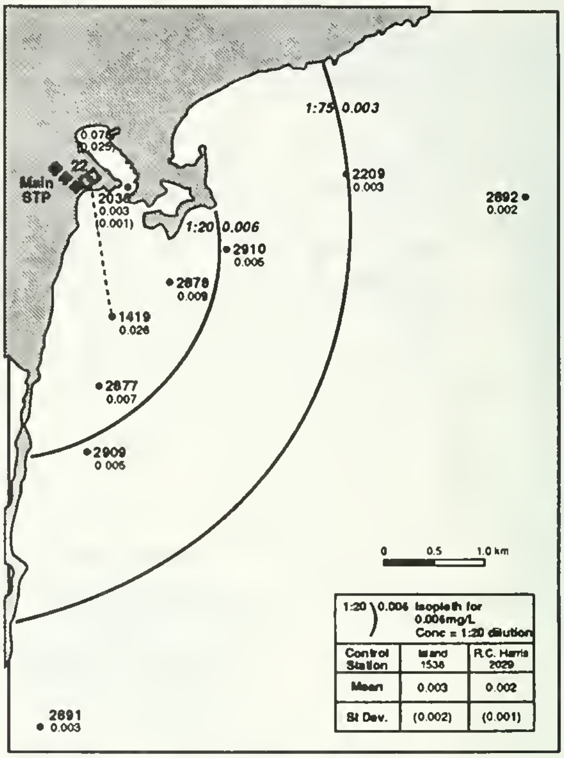
Conductivity (µmhos/cm) at 0.5m depth in 1987

Figure 3.12

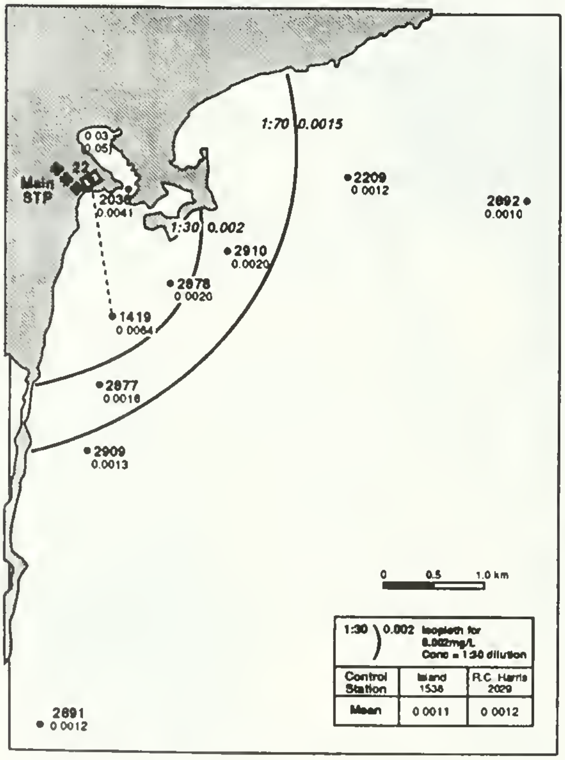
Spatial distribution of several heavy metals in 1987



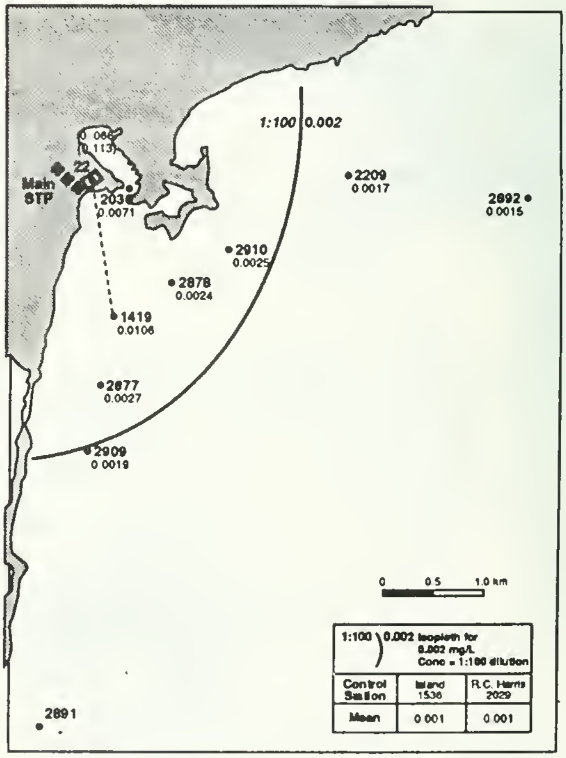
Iron (mg/L) at 0.5m depth in 1987



Manganese (mg/L) at 0.5m depth in 1987



Copper (mg/L) at 0.5m depth in 1987



Zinc (mg/L) at 0.5m depth in 1987

about 1.5 to 2 km of the outfall (1:50 dilution), slightly above the 0.03 mg/L background. Manganese is diluted to approximately 0.006 mg/L within 1 km of the outfall (1:20 dilution). These metals do not approach acute toxic levels, even at the Main STP outfall.

Concentration maps of these chemical parameters for 1986 do not permit isopleth construction since sampling in the Main STP area was confined to the immediate vicinity of the outfall (Stations 1419, 1431, 1432, 1433 and 1434). Maps illustrating those data, and computed X values, are included in Appendix 3. Generally, sampling was later in the day in 1986 (1300. to 1500 hrs.) Total ammonia concentrations at Station 1419 were similar to those in 1987 at 0.5 m (approximately 7 mg/L), but higher than in 1987 at 6 m (1.9 vs. 0.28 mg/L measured in the field). Phosphorus concen-trations were essentially the same (0.19 vs. 0.18 mg/L at 0.5 m). Residual chlorine concentrations were nominally higher in 1986 than 1987 (973 vs. 332 μg/L at 0.5 m); however, the difference was not statistically significant). While the main contributors to toxicity (chlorine and ammonia) were found at slightly higher average con-centrations in 1986, this may be due to sampling later in the day.

3.2.3 Plume Tracking

Surface movement of the Main STP outfall plume was tracked during the summers of 1984 and 1986 by Gore and Storrie using multiple drogue releases (Gore and Storrie, 1986b). These drogue trackings show the movement of water particles near the water surface and permit the calculation of dispersion characteristics at the existing outfall site as well as potential locations for the proposed outfall. It was found that for the existing outfall location, the predominant surface movement was northeastward (towards the Eastern Beaches), although southward movement parallel to the shore of the Eastern Headland was frequently observed. At the proposed offshore locations, the surface movement towards the Eastern Beaches was much less and the offshore movement component was much larger than at the existing location. The offshore location was also characterized by better dispersion than the present location. Further details of the studies are available elsewhere (Gore and Storrie, 1986b).

In order to map the extent of the Main STP plume in greater detail than that obtained by sampling at fixed locations, a plume tracking survey was undertaken for four days in June 1986. The plume- tracking vessel was equipped with a submersible pump attached to a towed "fish". This enabled a continuous record of temperature, conductivity and fluorescence (calibrated to represent turbidity) to be measured by on-board sensors and stored on an on-board computer. In addition, frequent water samples obtained from the submersible pump were analyzed on board ship for ammonia and chlorine residual. Vessel position was monitored by Loran, the readings of which were also stored on the on-board computer.

Of the four survey days, June 18 and 19 have been chosen for discussion here. June 18 represents stagnation conditions (average currents = 1.3 cm/s towards the north as measured by a drogue launched near the outfall and tracked during the survey). June 19 represents jetting conditions (average currents = 12 to 21 cm/s to the northeast as measured by a current meter located about 4 km southeast of the outfall). Spatial contour maps of conductivity, ammonia and chlorine residual on the two survey days are presented in Figures 3.13 - 3.15. In these figures, the marker at the southern tip of the east arm of the headland is used as a reference location for distance measurements. Contour maps for June 16 and 17 are presented in Appendix 5.

Concentrations of the three parameters contoured here in the Main STP effluent were similar on June 18 and 19; hence average values are used here in the discussion (conductivity = 1015 μmho/cm; ammonia = 21.0 mg/L; chlorine residual measured in the effluent line before discharge to the lake = 1050 μg/L). Average background conductivity was found to be 313 μmho/cm; background ammonia and chlorine residual were both assumed to be zero. Using these average values, the dilution factors (X in section 3.2.2) for the contour values used in the figures are as follows:

Figure 3.13a

Conductivity isopleths (µmho/cm) during plume tracking June 18, 1987, 11:30-16:30 h

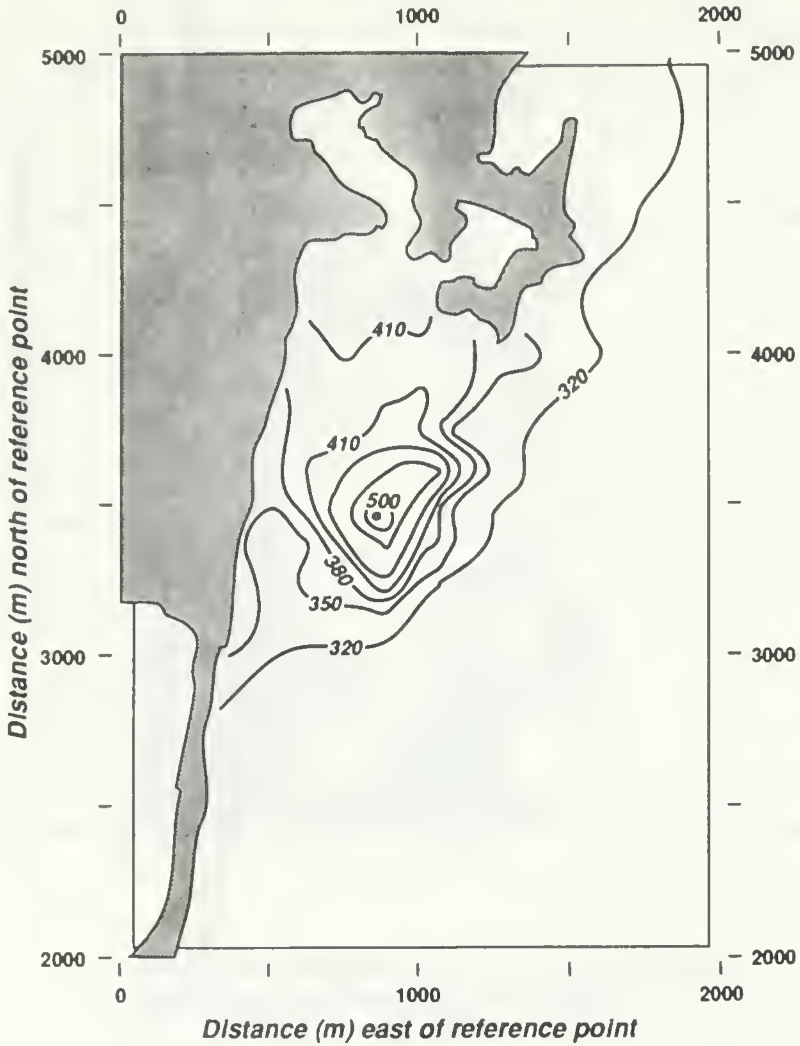


Figure 3.13b

Conductivity isopleths (µmho/cm) during plume tracking June 19, 1987, 11:00-14:00 h

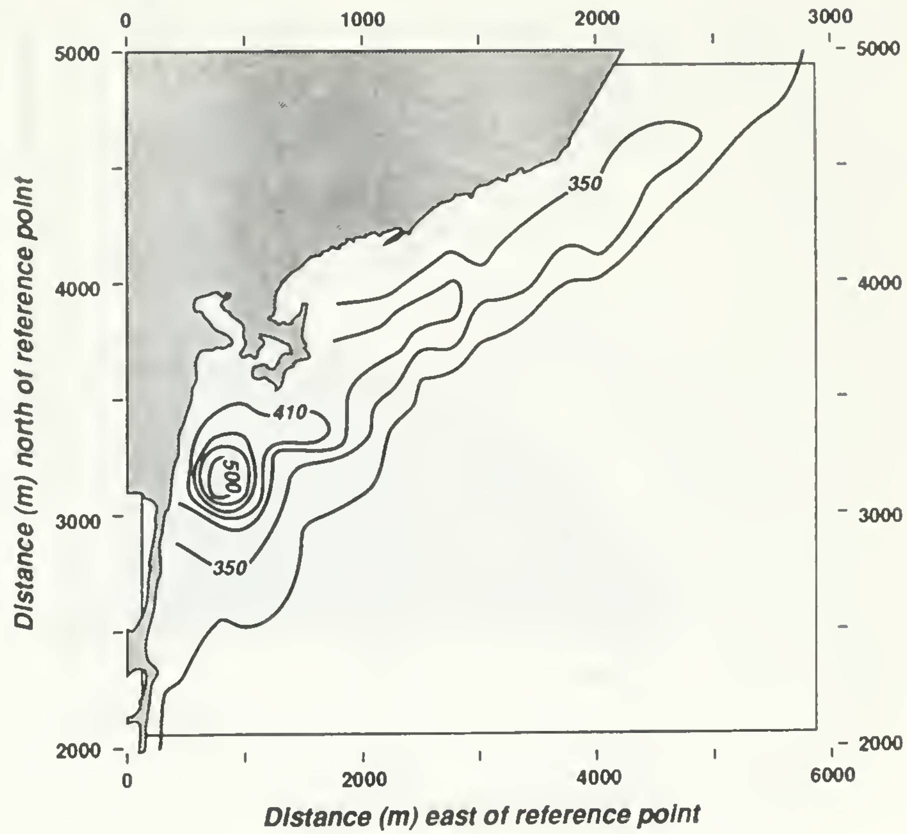


Figure 3.14a

Ammonia-N isopleths (mg/L) during plume tracking June 18, 1987, 11:30-16:30 h

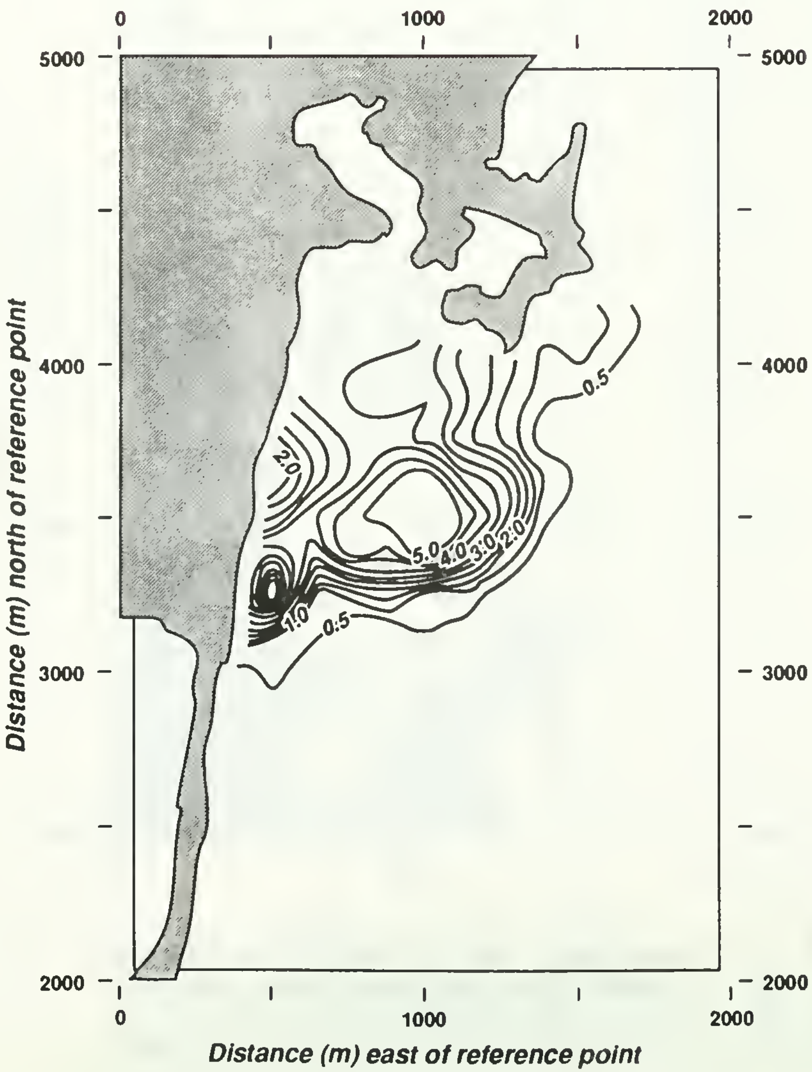


Figure 3.14b

Ammonia-N isopleths (mg/L) during plume tracking June 19, 1987, 11:00-14.00 h

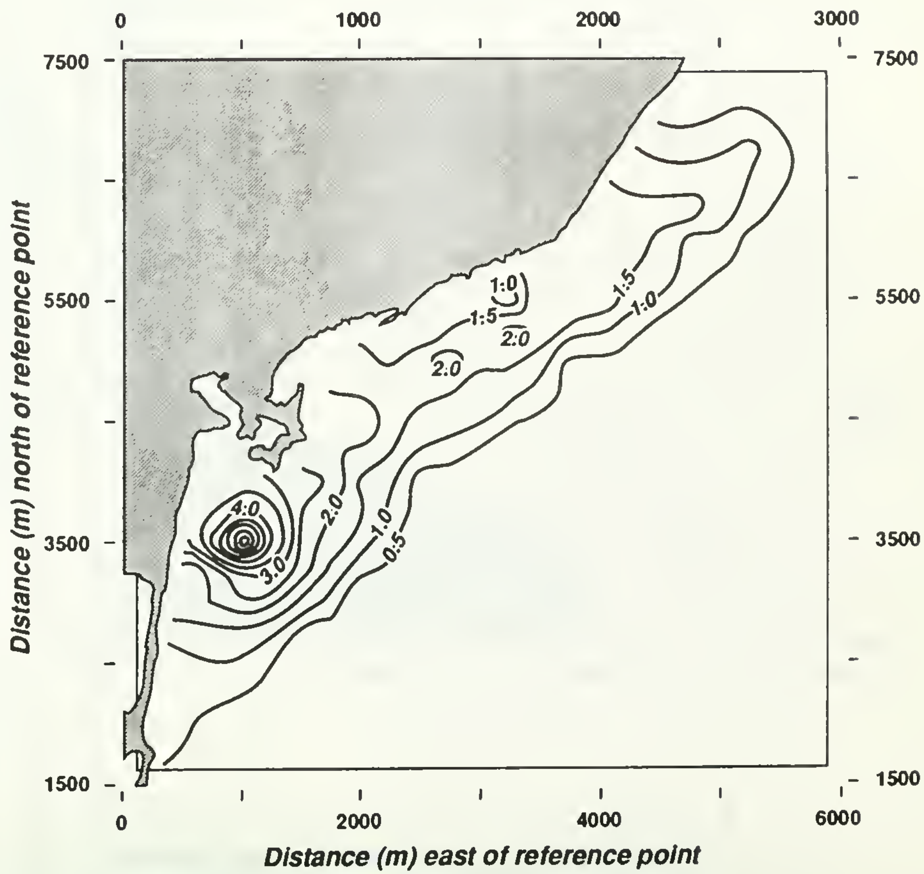


Figure 3.15a

Chlorine residual isopleths (µg/L) during plume tracking June 18, 1987, 1130-1630 h

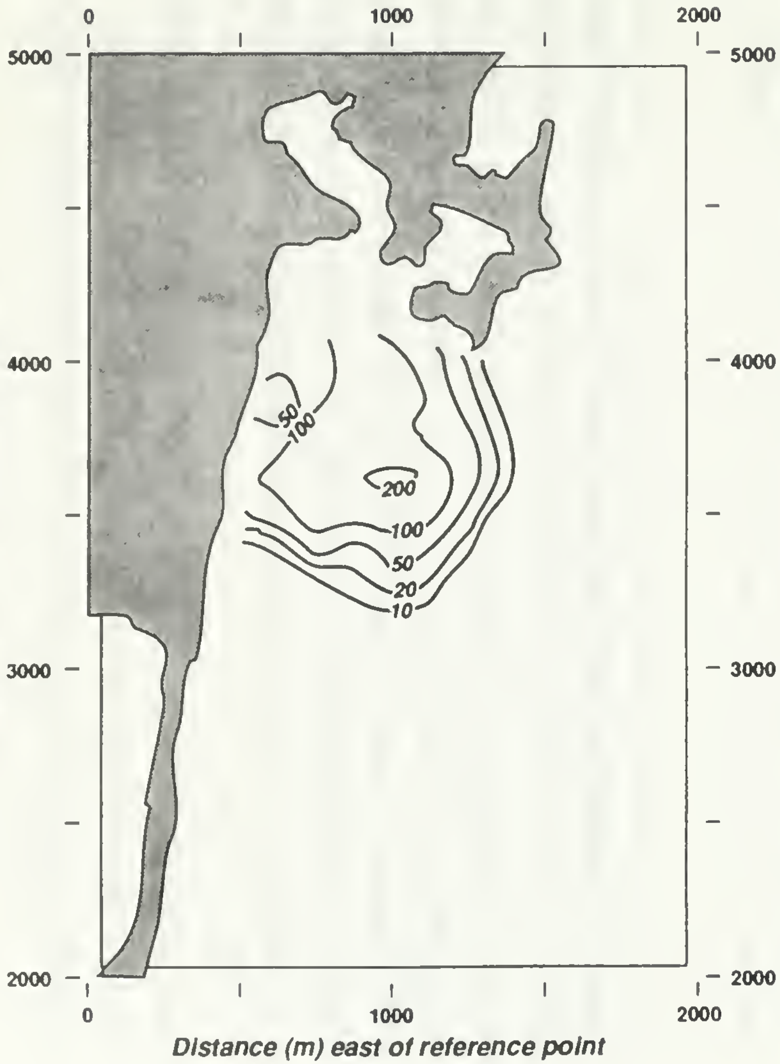
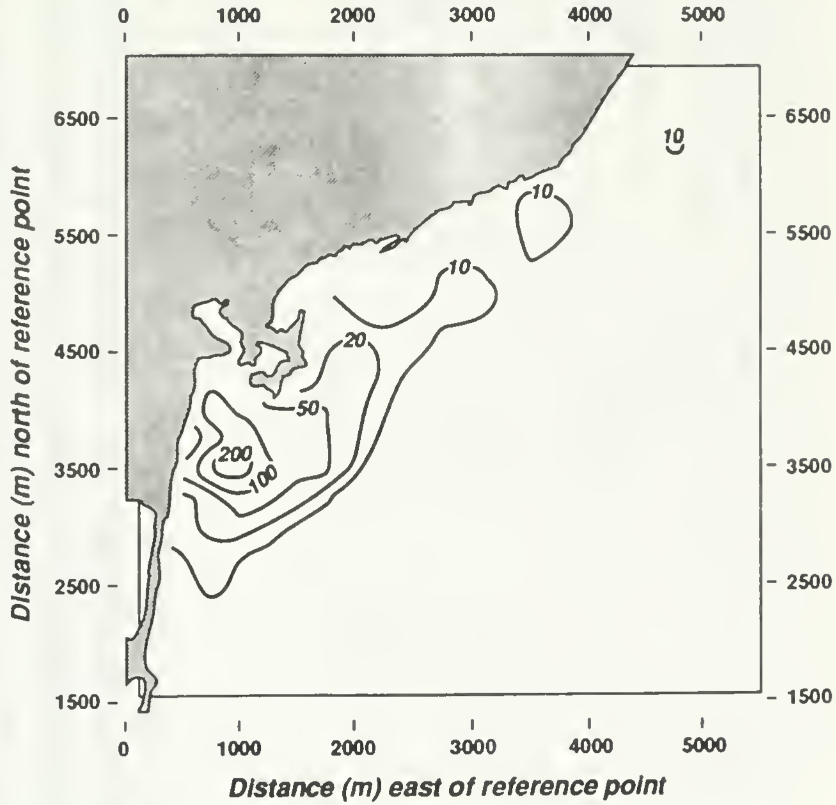


Figure 3.15b

Chlorine residual isopleths (µg/L) during plume tracking June 19, 1987, 1100-1400 h



Conductivity (μmho/cm)		Ammonia (mg/L)		Chlorine residual (μg/L)	
Contour Value	X	Contour Value	X	Contour Value	X
320	100.	0.5	42.	10	100.
350	19.	1.0	21.	20	53.
380	10.5	1.5	14.	50	21.
410	7.3	2.0	10.5	100	10.5
440	5.5	2.5	8.4	200	5.3
470	4.5	3.0	7.0		
500	3.8	3.5	6.0		
		4.0	5.3		
		4.5	4.7		
		5.0	4.2		

Under stagnation on June 18, dilutions for conductivity and ammonia increase to 1:100 within 1 km of the outfall close to shore and 0.5 km of the outfall away from shore. As a consequence of its rapid decay, dilutions for chlorine residual (Figure 3.15a) reach 1:100 within about 0.5 km to the northeast and 0.3 km to the southeast of the outfall. A mild elevation of conductivity towards Coatsworth Cut (X = 5.5 to 7.3) suggests entrapment of a portion of the plume in this area, or possible input from Coatsworth Cut itself.

Under jetting conditions towards the northeast (Figures 3.13b - 3.15b), a plume lying a few hundred metres offshore from the Eastern Beaches was observed. For conductivity and ammonia, X values of about 20 extend for 5 to 5.5 km from the outfall (and including the area of the R.C. Harris WTP intake); 1:10 dilution is observed up to 3 km from the outfall, although its zone is somewhat patchy in nature between 1.5 and 3 km. This may reflect either short-term variation in outfall discharge and lake currents, or limitations associated with the area surveys, or both. As expected, the chlorine residual plume is again shorter (1:20 dilution at 1 km and 1:100 at 3 to 4.5 km from the outfall; figure 3.15b).

These results provide a greater detail of resolution over short-interval time scales (order of hours) than the averaged results presented in section 3.2.3. In addition, they show the variability in plume size resulting from extremes of current regimes. (See also results for

June 16 and 17, appendix 5). The averaged results for conductivity (figure 3.11d) and ammonia (figure 3.10a-c) show zones for 1:20 and 1:100 dilution similar to or slightly larger than those observed under stagnation (figures 3.13a - 3.15a); however, due to the combination of northeastward and southwestward current conditions, the averaging procedure combines lower (downstream) with higher (upstream) X values. In particular, the reduced dilution factors resulting from jetting (figures 3.13b - 3.15b) which occurs only a small proportion of the time are completely obscured by the averaging process. Additionally, the results in this section provide improved definition of the rate of dilution in the offshore (southeast) direction. Dilution in this direction is generally good, with X values of 1:20 to 1:100 being observed within 0.5 km of the outfall on most survey days.

3.2.4 Exceedence Frequencies

Exceedence frequencies are included in Appendix 2 for all stations sampled in 1986 and 1987. Tables 3.17 and 3.18 present a summary of exceedence frequencies at Station 1419, the Main STP outfall, at 0.5 and 6 m water depths. All chemical parameters which exceeded their PWQOs in receiving water are included.

1987

The PWQO for unionized ammonia (0.02 mg/L) was exceeded in 75% of 0.5 m samples over the Main STP outfall (Station 1419) in 1987 (Figure 3.16). This percentage is based only on samples for which pH and temperature were also determined, since both these parameters are needed to calculate unionized ammonia from the total measured value. Percent exceedence declines with distance from the outfall and is zero at both control stations (1536 and 2029). Exceedence isopleths (Figure 3.16) suggest that less than 50% of samples exceeded the PWQO at any point greater than 1 km from the outfall. No ammonia exceedences were detected in samples from a 6 m depth at the outfall, although only three samples had concurrent ammonia, pH and temperature measurements.

TABLE 3.17: EXCEEDENCE OF CONVENTIONAL AND METAL WATER QUALITY OBJECTIVES AT STATION 1419 OVER THE MAIN STP OUTFALL

(see Appendix 2 for complete statistical summary)

Parameter	1986 N	1986 %	1987 N	1987 %	PWQO[1]
0.5 m Depth					
Residual Chlorine***	7	100	13	70	2.0 µg/L
Field Ammonia	6	100	12	75	0.02*
Lab Ammonia	6	100	-	-	0.02*
Phosphorus	10	100	14	100	0.02
Iron	10	40	13	77	0.30
Copper	10	30	13	38	0.005
Cadmium	10	20	13	31	0.2 µg/L
Lead	-	-	13	0	0.025**
Nickel	10	0	13	0	0.025
Mercury	9	11	13	8	0.2 µg/L
6 m Depth					
Residual Chlorine***	6	100	5	0	2.0 µg/L
Field Ammonia	6	67	8	0	0.02*
Lab Ammonia	6	50	-	-	0.02*
Phosphorus	10	80	4	100	0.02
Iron	9	22	4	25	0.30
Copper	9	11	4	25	0.005
Cadmium	9	11	4	25	0.2 µg/L
Lead	-	-	4	0	0.025**
Nickel	9	0	4	25	0.025
Mercury	8	0	4	0	0.2 µg/L

[1] PWQO in mg/L unless otherwise indicated; phosphorus value is a guideline only.
* Ammonia objective is for unionized fraction.
** Lead objective is alkalinity-dependent; alkalinity = 80 mg/L was assumed.
*** Chlorination period (to end of September) only.

TABLE 3.18: EXCEEDENCE OF PROVINCIAL WATER QUALITY OBJECTIVES FOR ORGANOCHLORINE PESTICIDES AT STATIONS 1419, 1536 AND 2029

Parameter	1986 N	1986 %	1987 N	1987 %	PWQO (µg/L)
STATION 1419					
Surface (0 to 1 m Water Depth)					
Lindane	10	30	13	46	0.01
Heptachlor	10	0*	13	8	0.001
α-Chlordane	10	0*	13	0	0.06
Dieldrin	10	10	13	0*	0.001
Bottom (6 m or Depth of Turbidity Maximum)					
Lindane	9	11	5	0	0.01
Heptachlor	9	0*	5	0*	0.001
α-Chlordane	9	0*	5	0*	0.06
Dieldrin	9	11	5	0*	0.001
STATION 1536					
Surface (0 to 1 m Water Depth)					
Lindane	6	0	0	-	0.01
Heptachlor	6	0*	0	-	0.001
α-Chlordane	6	0*	0	-	0.06
Dieldrin	6	0*	0	-	0.001
STATION 2029					
Surface (0 to 1 m Water Depth)					
Lindane	6	0	0	-	0.01
Heptachlor	6	0*	0	-	0.001
α-Chlordane	6	0*	0	-	0.06
Dieldrin	6	0*	0	-	0.001

* Indicates chemical was never detected.

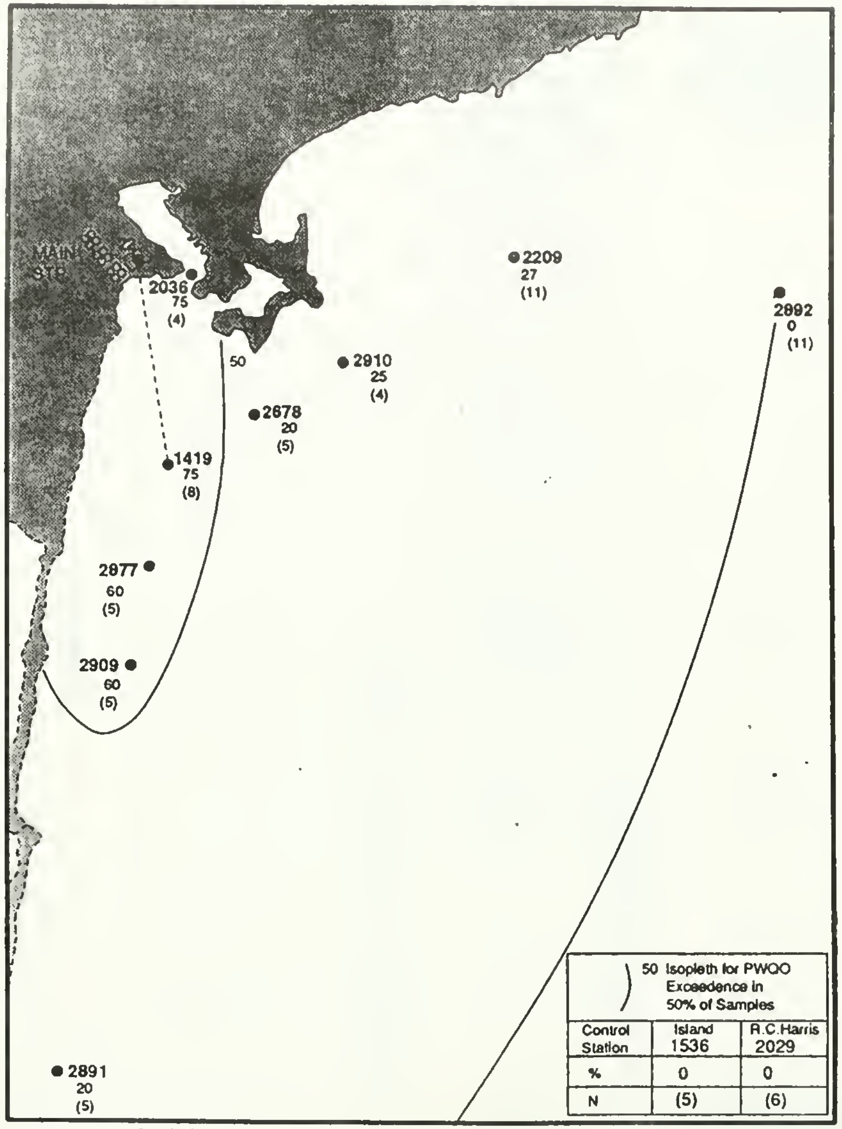


FIGURE **3.16a**
Field Ammonia Exceedence (%) at 0.5m Depth in 1987

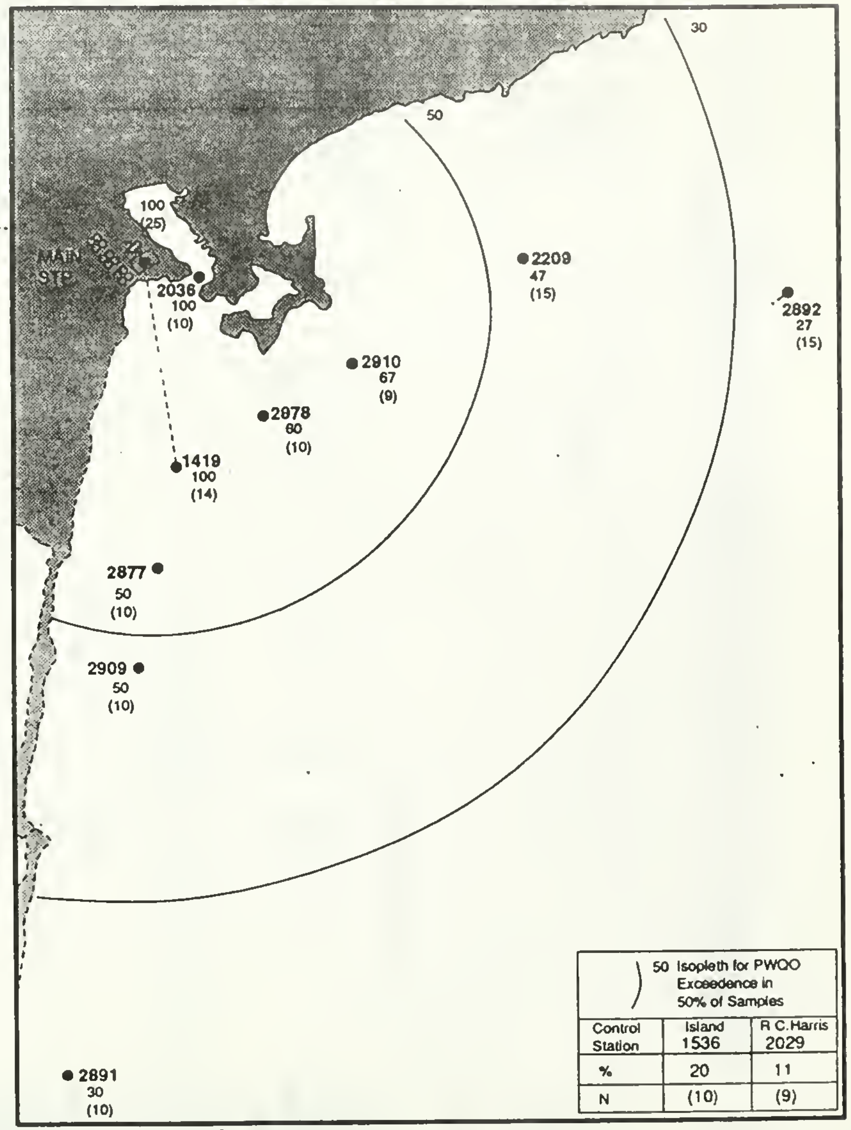


FIGURE **3.16b**
Phosphorus Exceedence (%) at 0.5m Depth in 1987

The phosphorus guideline (PWQG) for prevention of nuisance of algal growth (0.02 mg/L) was exceeded in all 0.5 m and 6 m samples at Station 1419 in 1987 (Figure 3.16). The frequency of exceedence in 0.5 m samples declined with distance from the outfall to 20% and 11% at control Stations 1536 and 2029, respectively. Exceedence isopleths (Figure 3.16) suggest that less than 50% of samples should exceed the PWQG at any point more than 1 km from the outfall. Few 6 m samples were analyzed for phosphorus at stations other than 1419.

Residual chlorine exceeded the PWQO of 2 μg/L in all station 1419 samples collected between June and September of both 1986 and 1987. Exceedence frequency declined with distance from the outfall, to about 5% of samples more than 1 km south of the outfall. STP chlorination ceases at the end of September. The PWQO is designed for chronic protection of aquatic life. Acute toxicity to rainbow trout was found to occur within 100 m from the outfall in as short a period as 4 h (Flood, 1990), and in 96 h at 500 m from the outfall. However, toxicity would not be expected beyond a radius of approximately 500 m from the outfall.

Industrial Waste Discharge Guidelines (MOE, 1987) were exceeded in 1987 only by cadmium in the Main STP effluent. However, most heavy metals (except mercury and chromium) exceeded PWQOs in the receiving water adjacent to the Main STP outfall (Station 1419) in 1987. Frequency of PWQO exceedence in 0.5 m receiving water samples was highest at the outfall Station 1419 for iron (77%), copper (38%) and cadmium (31%). Nickel exceeded its PWQO once only in a 6.0 m sample. In general, PWQO exceedences were rare and showed little spatial pattern beyond a 500 m radius from the outfall. Very few heavy metal exceedences (one each for iron and cadmium) were found in the clean water zone of the waterfront (Cluster 4, Section 3.3.1). None of the metal exceedences were in the acutely toxic concentration range.

1986

In 1986, exceedence frequencies showed the same general pattern as in 1987, although sampling in the Main STP area was confined to the immediate vicinity of the outfall (Station 1419). Residual chlorine objectives were consistently exceeded near the outfall; a single value at control Station 2029 (near the R.C. Harris WTP intake) was also in exceedence. The ammonia objective and phosphorus guideline for prevention of nuisance algal growth were usually exceeded near the outfall, with higher exceedence frequencies at surface samples than at 6 m water depths. Forty percent of the iron values were in exceedence at the surface, with less frequent exceedence at 6 m. Copper and cadmium values were occasionally in exceedence at the outfall. Main STP effluent occasionally exceeded the 1 mg/L objective for STP phosphorus.

Organochlorine pesticides (lindane and heptachlor) occasionally exceeded PWQOs in receiving water at the Main STP outfall (Station 1419). Table 3.18 lists all the pesticides detected in receiving water, and their percent exceedence at Stations 1419, 1536 and 2029 (the R.C. Harris control station). Exceedence frequencies were greater in 1987 than in 1986, and greater in surface samples (0 to 1 m) than bottom samples (6 m or depth of turbidity maximum) at the outfall. Lindane exceedence in the STP effluent (Station 22) was 86% in 1986 and 100% in 1987. Heptachlor exceedence at 0.5 m in the effluent was 29% in 1987. There were no heptachlor exceedences in 1986.

3.2.5 Depth Profiles

The results presented for the plume area in the previous two sections for water depths of 0.5 m and 6 m suggest consistently better water quality near the bottom than at the surface. In order to determine whether there is any significant subsurface plume (maximum concentration below 0.5 m), the monthly mean conductivities were plotted against water depth to give a depth profile for each contaminant at each station.

The depth profile for conductivity at the Main STP outfall (Station 1419) shows a distinct surface maximum at all times of year (Figure 3.17), while conductivity at the control Stations 1536 and 2029 shows no consistent pattern. The stations immediately surrounding the STP outfall (1431, 1432, 1433, 1434) tend to show a surface maximum, at most times, and thus resemble the outfall (Figure 3.18).

In 1987, the depth profiles for conductivity at the Main STP outfall (Station 1419) and the Humber Bay STP outfall (Station 2072) both displayed a distinct surface maximum (Figure 3.19). Profiling at stations immediately surrounding the Main STP outfall was limited in 1987, but the results obtained showed similar surface maximum to those in 1986 (Figure 3.18).

Other stations on the waterfront which were subjected to profile sampling failed to show this pattern, or any other consistent pattern. The STP effluent apparently rises quickly to the surface, since it is warmer than the receiving water at depth, but the plume loses any consistent depth dependence within a few hundred metres.

3.2.6 Fugacity Analysis of Toxicity Potential

As indicated in Sections 3.2.2 and 3.2.4, the major sources of toxicity in the vicinity of the Main STP outfall are free chlorine and ammonia, and toxic effects are likely to be confined to within a 500 m radius of the outfall. While there are exceedences of heavy metal and organochlorine pesticide water quality objectives at the outfall (Station 1419), concentrations of these contaminants in water do not approach toxic levels.

Mackay et al. (1987) have devised an index (y) of toxicity potential suitable for application to non-polar organic contaminants:

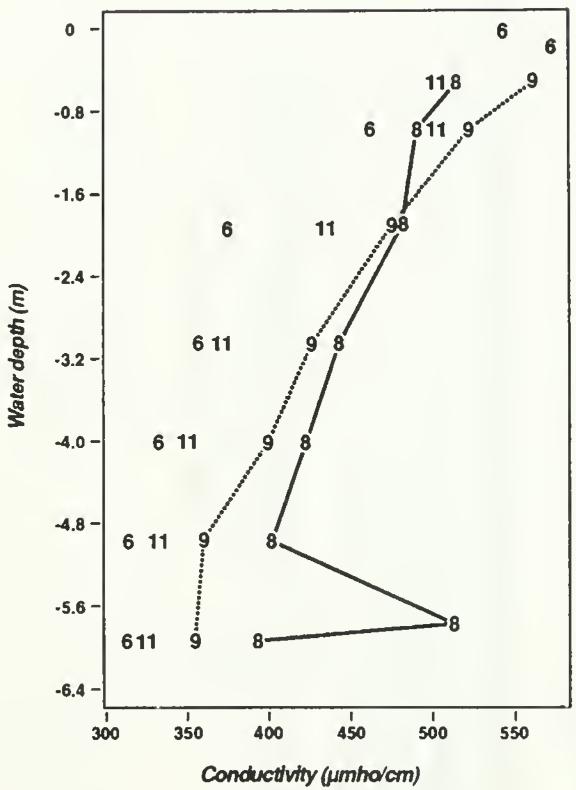
$$y = (K_{ow})^{0.8} C_w \, MV \, 10^{-6}$$

where: K_{ow} = octanol-water partition coefficient,
C_w = chemical concentration in water (g/m^3), and
MV = molar volume (cm^3/g).

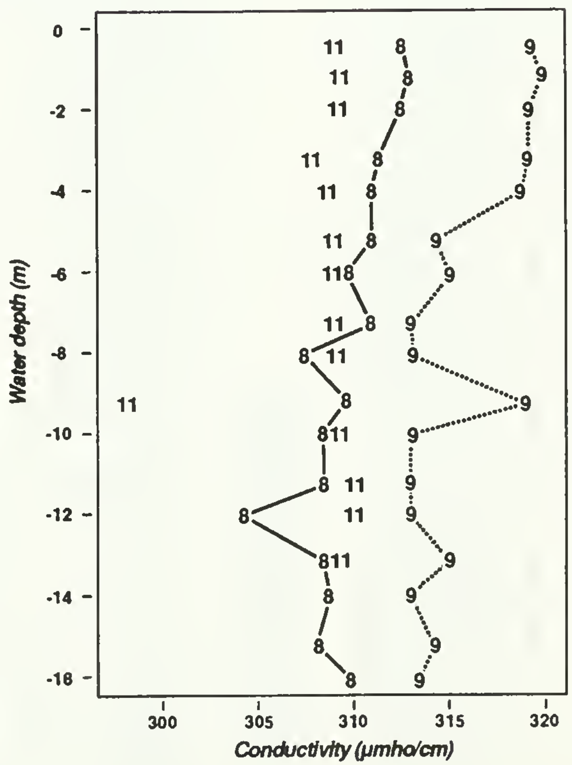
Figure 3.17

Conductivity - depth profiles at stations 1419, 1536 and 2029 in 1986

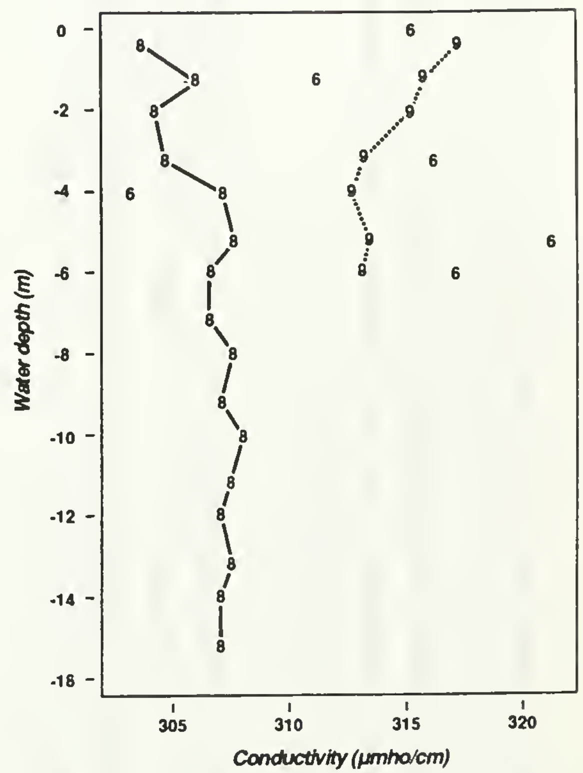
(Plot symbols indicate month)



Conductivity vs water depth at Station 1419 in 1986

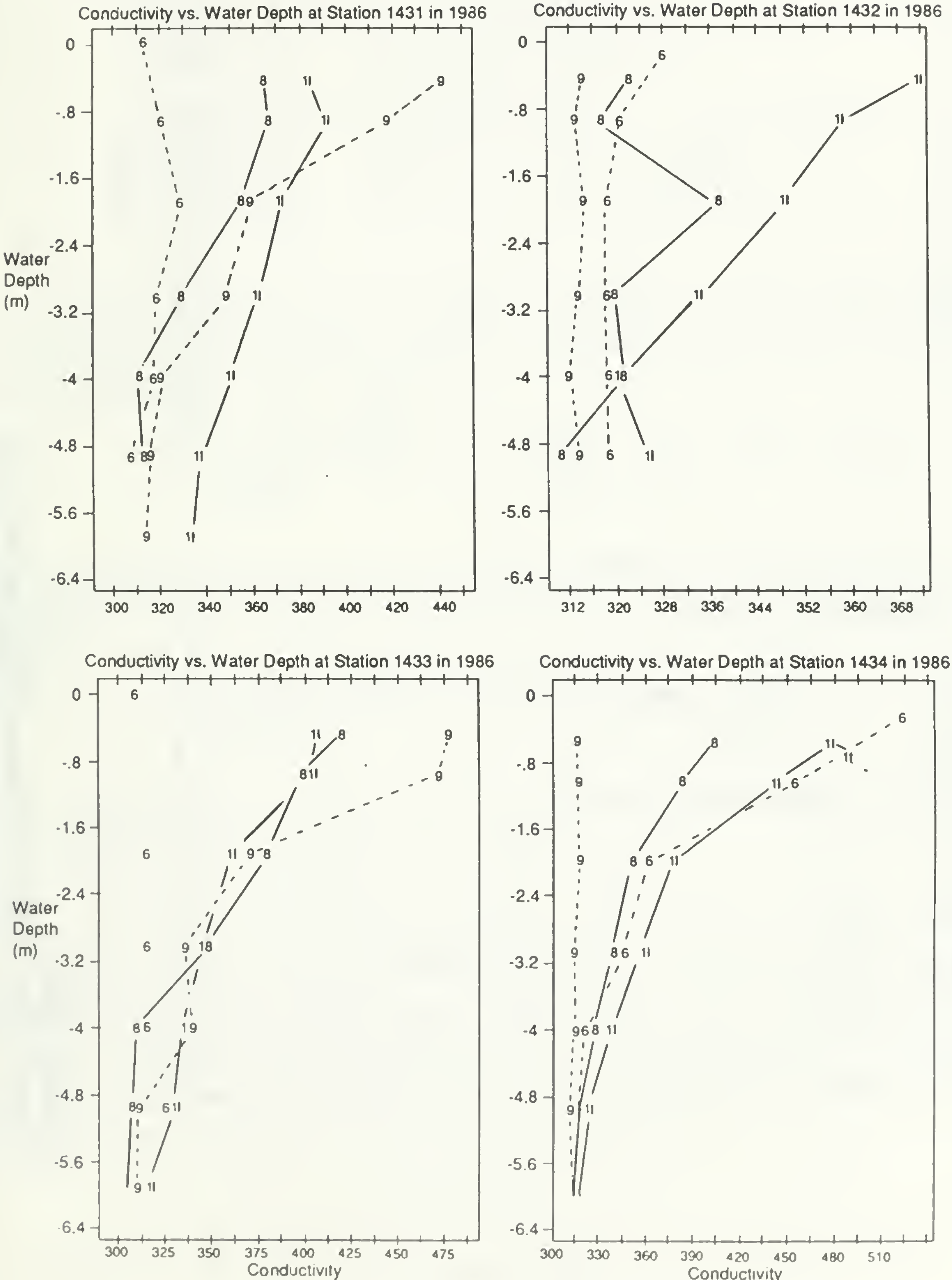


Conductivity vs water depth at Station 1536 in 1986



Conductivity vs water depth at Station 2029 in 1986

FIGURE 3.18
Conductivity Depth Profiles at Stations 500 m From Main STP Outfall in 1986 (plot symbols indicate month)



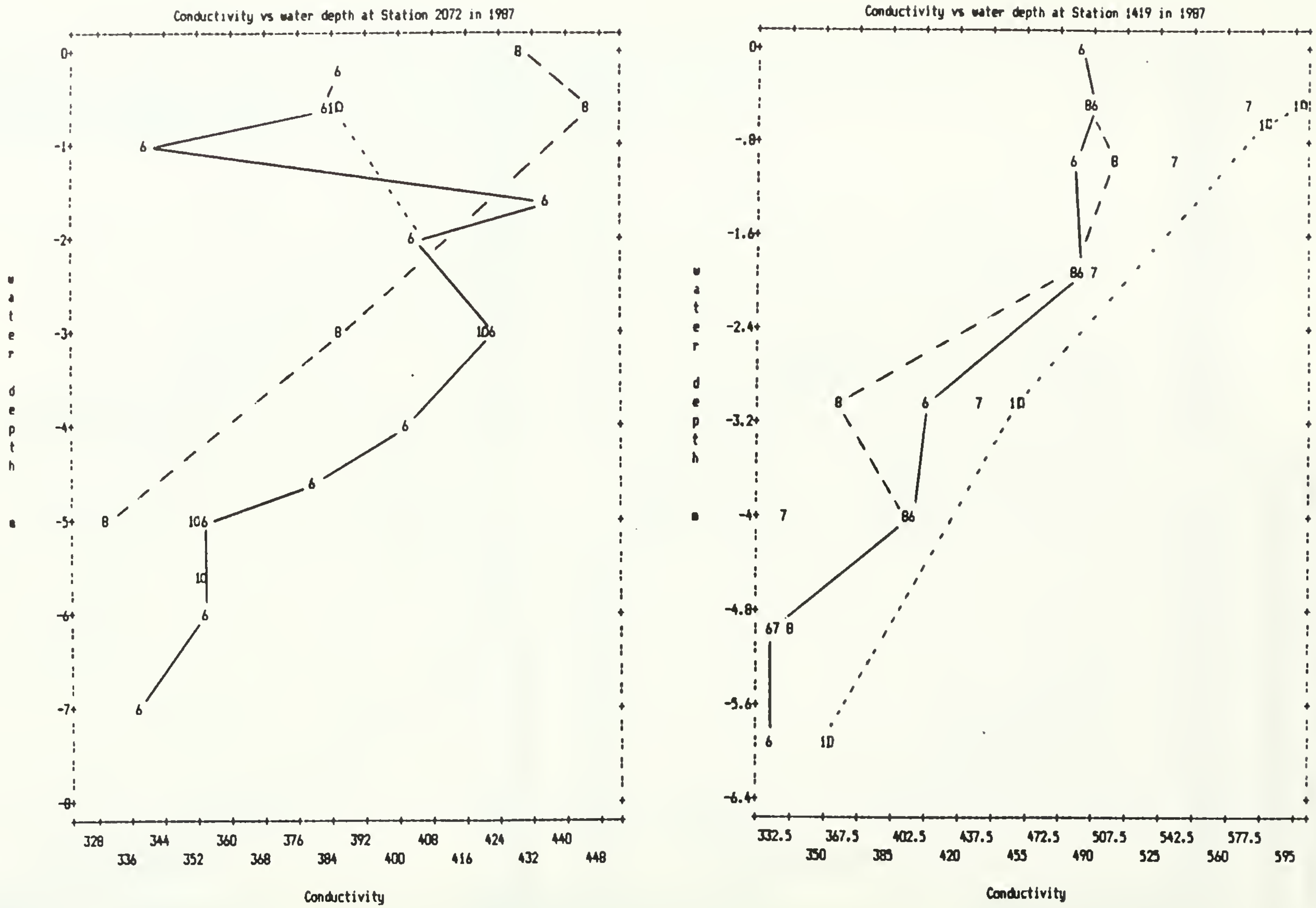


FIGURE 3.19
Conductivity Depth Profiles at Stations 1419 and 2072 in 1987 (plot symbols indicate month)

Interpretation of this index is as follows:

y greater than 0.01:	acute effects virtually certain,
0.01-0.001:	acute effects possible,
less than 0.001:	acute effects probably absent,
greater than 0.001:	chronic effects certain,
0.001-0.0001:	chronic effects probable,
0.0001-0.00001: and	chronic effects unlikely, but possible,
less than 0.00001:	chronic effects almost certainly absent.

We computed this index for lindane which was the only organic contaminant frequently in exceedence of the PWQO for receiving water at the Main STP outfall. Using the maximum concentration recorded at the outfall (Station 1419) in 1987:

$$\begin{aligned} y &= (2238.7)^{0.8}\ (0.000021\ \text{mg/L})\ (224)\ 10^{-6} \\ &= 0.000002 \end{aligned}$$

Thus, chronic toxic effects on biota would be almost certainly absent at the maximum concentration observed. Using the average concentration at the outfall (10.02 ± 3.92 ng/L) in 1987:

$$\begin{aligned} y &= (2238.7)^{0.8}\ (0.000010\ \text{mg/L})\ (224)\ 10^{-6} \\ &= 0.000001 \end{aligned}$$

This average concentration, equal to the PWQO, is an order of magnitude lower than the concentration at which chronic effects would be possible.

Perusal of a limited quantity of APLE data also shows that lindane is the only organic contaminant present in the vicinity of the Main STP at levels approaching PWQOs for receiving water or other levels of concern to aquatic biota. Average concentrations at offshore stations were approximately 1 ng/L, or an order of magnitude lower than at the Main outfall. Maximum concentrations observed for Main and Humber STP effluents were 56 and 66 ng/L, respectively.

3.2.7 Interparameter Correlations With Main STP Effluent Data

The obvious proximity of water quality impact zones (Section 3.3.1) to known point sources implies that the associated point source is responsible. However, quantitative prediction of lake concentra- tions of specific contaminants from the concentrations of those contaminants measured in the point source effluent is complicated by variation in source flow and loading, variation in lake current speed and direction, and a variable time lag between contaminant discharge and arrival at a given location in the lake. As a result, simple lake vs. source correlations or regression equations may have little predictive power.

Lake vs. source correlation coefficients are tabulated in Table 3.19. These coefficients represent a simple linear model. The first row represents all lake stations, without a time lag, based on Main STP study data. Under these conditions, only conductivity was significantly correlated with the STP source ($r = 0.59$). There was a seasonal trend in conductivity on the waterfront (Section 3.3.4) which may be reflected, to some extent, in the Main STP.

There are insufficient Main STP study data to examine correlations between the STP effluent and the outfall Station 1419 above (only two samples match to the nearest hour). However, the Metro Works Department daily composite samples were collected morefrequently and can be matched with daily average concentrations of contaminants at the outfall. In addition, daily loadings (average flow x composite concentration) can be matched with outfall concentrations.

No source vs. outfall correlation was found for phosphorus, using daily average data, because there is much less day-to-day variation in phosphorus.

Most of the phosphorus variation is related to fluctuating conditions of relatively short duration. Thus, source and outfall concentrations measured frequently and at matching times over the course of the day are needed to develop a predictive model.

TABLE 3.19: CORRELATION OF LAKE AND MAIN STP CONTAMINANT CONCENTRATIONS AND LOADINGS

Lake Data Set	STP Data Set	Correlation Coefficient for Chemical Parameter					
		Conductivity	DOC	COD	Suspended Solids	Total Ammonia	Total Phosphorus
1987 (0.5 m)							
Study Data All Stations	Study Data Grab Concentration	0.59* (28)	0.12 (28)	0.01 (28)	0.07 (28)	-0.10 (25)	0.03 (28)
Study Data Station 1419	Metro Data Composite Concentration	-	-	-	-0.37 (13)	0.76* (7)	-0.27 (14)
Study Data Station 1419	Metro Data Daily Loading	-	-	-	-0.38 (11)	0.15 (6)	-0.20 (12)

*indicates statistical significance of one-tailed test ($p < 0.01$).

(n) indicates number of lake-STP paired observations, matched to the nearest hour in row 1, to the nearest day in rows 2 and 3.

Data suitable for development of a short-term predictive model are presently quite limited. To extend such a model beyond the outfall, appropriate time lags must be identified. A model based on available data is discussed in Section 4.2.

3.2.8. Short-Term Correlation of Source Loading and Receiving Water Conductivity

Correlating the instantaneous source loading and receiving water conductivity establishes whether receiving water conductivity is predictable over the short-term from instantaneous source loading. Given an approximately steady-state source, it is possible to correlate the source load to the receiving water conductivity after subtracting an appropriate time-lag from the receiving water time based on the average velocity from 1419 to 2891 and 1419 to 2209 and the distance to a particular station. The conductivity data for receiving water in 1987 were thus shifted back in time and correlated to the source loadings at the same times (within a one-hour time window):

$$\text{Receiving Water Conductivity}_{T=\text{TimeMeasured-TimeLag}} \text{ vs. }$$
$$\text{Source Load}_{\text{TimeT}}$$

The source load and receiving water conductivity were correlated for:

- o a data set extending south of the outfall (1419, 2877, 2909), and
- o a data set extending east of the outfall (1419, 2878, 2910).

The expected result would be a positive correlation along each direction which decreases with increasing distance. The results obtained show a non-significant correlation over this entire spatial domain. We then reduced the domain to include only stations 1419, 2877 and 2878. Again, there was no significant correlation. The correlations are negative for loading, indicating that as the loading increases the receiving water conductivity decreases.

The correlations are larger in the eastern direction which is the direction of the most persistent current (i.e. largest mean vector component; Gore and Storie, 1986a). Finally, we examined the source vs. outfall correlation (no time lags involved), and obtained similar results. These results are summarized in Table 3.20.

Since the source loadings are quite variable, a possible reason for the lack of source vs. receiving water correlation is the low frequency of sampling and the paucity of time-matched source and receiving water data. For example, in 1987 at the outfall itself, approximately 40 measurements were taken irregularly over a four-month period. Sampling rate should be directly proportional to temporal variation in source loading (i.e. concentrated at the most dynamic time of day), and sampling should include the entire daily range in order to optimize the study design for time series correlation.

Since receiving water conditions (current, wind, weather) may vary considerably from day-to-day, the assumption of a constant time lag may also be inappropriate for the available data, which includes few samples on any one day. Intensive sampling over a short period of time (e.g., one day) would be more appropriate for development of short-term predictive models.

Another possible reason for the lack of correlation at the outfall itself is that the outfall flow dominates the water volume in this vicinity. In such a system, receiving water concentrations should be correlated with source concentrations rather than loadings. Short-term prediction of receiving water concentrations from source concentrations is discussed in Section 3.2.9.

TABLE 3.20: SHORT-TERM CORRELATION OF MAIN STP EFFLUENT AND ADJACENT RECEIVING WATER CONDUCTIVITY, 1987

Receiving Water Data Set	Time Lag (hrs.)	Loading	Conductivity
Stn 1419 (outfall)	0	-0.93 (5)[1]	-0.25 (7)
Stn 1419-2877 (N-S)	1.2	-0.54 (8)	0.41 (10)
Stn 1419-2878 (E-W)	1.8	-0.71 (7)	0.59 (9)
Stn 1419-2909 (N-S)	2.2	-0.34 (10)	0.36 (12)
Stn 1419-2910 (E-W)	3.9	-0.51 (8)	0.47 (10)

[1] (n) indicates number of time-matched sample pairs within a one-hour time window.

3.2.9 Short-Term Correlation of Source and Receiving Water Conductivity

Correlating the instantaneous source conductivity and receiving water conductivity establishes whether receiving water conductivity is predictable from source conductivity. As a stable chemical parameter, conductivity is more likely to be predictable than a chemical subject to degradation, volatilization or precipitation. The same methods described in Section 3.2.8 were used, except that source loading was replaced with source conductivity. Correlations were examined for:

$$\text{Receiving Water Conductivity}_{T=\text{TimeMeasured-TimeLag}} \text{ vs. Source Conductivity}_{\text{TimeT}}$$

The results are included in Table 3.20. Again, no significant correlations were found either at the outfall, or over a broader spatial domain in the outfall vicinity.

As outlined in Section 3.2.8, sample size were small, and allocation of sampling effort was sub-optimal for time series correlation. Moreover, the sampling effort captured only a small portion of the possible variation in conductivity. For example, neither the source or outfall water varied by more than 100 umhos/cm, in the few time-matched samples. However, the STP effluent varied by more than 300 umhos/cm over the long-term.

3.3 Lake Ontario, Toronto Waterfront Area

In 1987, a fixed-grid survey encompassing the entire Metro Toronto area from Pickering to Lakeview was undertaken. The purpose of this survey is to provide further baseline data on water quality across the entire Metro Toronto Waterfront, including the impact on the lake of all pollution sources, not just the Main STP. Additionally, this survey provided an update on water quality zonation (previously obtained only for the central waterfront area - Poulton and Griffiths, 1986), as well as input data for the RAND currents and water quality model and TOXFATE fate and transport model of organic contaminants. In this section, the analysis of spatial zonation in water quality is discussed, including the average water quality of each zone and its variability.

Data collected in 1986 are not considered here, as sampling was much more restricted to the immediate vicinity of the Main STP.

3.3.1 Spatial Zonation

The analysis of variance model first developed by El-Shaarawi and Kwiatkowski (1977) was used as a starting point in the zonation analysis. This model breaks down the variance in the observation for any one chemical parameter (variable) into between- station and between-cruise portions. The following set of transformations (Box and Cox, 1964) are first applied to the data in order to satisfy the assumption of normal distribution required for the use of parametric methods such as analysis of variance:

$$Z_{ij} = (Y_{ij}^{\lambda\ -1})/\lambda \quad (\lambda = 0)$$

$$Z_{ij} = \ln Y_{ij} \quad (\lambda = 0)$$

where: Y_{ij} = observed water quality at station j during cruise

Z_{ij} = transformed observation, and

λ = transformation parameter.

The method of maximum likelihood is used to estimate the value of λ which produces the best approach to normal distribution of Z_{ij} for each parameter.

The mean value of Z_{ij} is then resolved into additive components as follows:

$$E(Z_{ij}) = u + \alpha_i + \beta_j$$

where: u = general mean,
α_i = between-cruise (temporal) effect, and
β_j = between-station (spatial) effect.

For each parameter for which the station effects β_j are significant according to an F- test with (j-1) and (ij-1) degrees of freedom, the β_j were used as water quality observations in multivariate analysis of water quality zones. Other parameters were excluded from the analysis.

The water quality zonation analysis involved use of principal components analysis followed by cluster analysis, using a methodology similar to that first applied to Lake Ontario by Neilson and Stevens (1986) and Poulton and Griffiths (1986).

Many of the chemical variables (station effects) are correlated with each other as they are often controlled by similar causative factors. Principal components (PC) analysis is used to transform such correlated data by finding linear additive functions of these variables which give a smaller number of new uncorrelated variables (PCs). Each of these PCs is a linear additive function of the original variables, with the first variable accounting for the largest proportion of variance in the original data, and the second variable accounting for the next largest amount of variance, and so forth. The PCs are derived so as to be independent of (i.e. uncorrelated to) previously derived components; therefore, each component provides unique information about the original data set. They also tend to be more normally distributed than the original variables (station effects), although these station effects, as derived from El-Shaarawi and Kwiatkowski's (1977) model, tend to be reasonably

normally distributed, provided an appropriate transformation index has been selected.

Factor scores are calculated from the components for each station j and principal component k as follows:

$$S_{jk} = \sum_{m=1}^{p} \beta_{jm} C_{mk}$$

where: m = parameter index,
p = total number of parameters,
β_{jm} = station effect in parameter m at station j (as calculated earlier), and
C_{mk} = loading coefficient for parameter m on factor k.

Cluster analysis was used to classify the stations into groups with similar factor scores from the principal components analysis.

Alternatively, cluster analysis can be applied directly to the station effects; however, the result may be biased by the presence of highly correlated parameters as explained above. The method used was a hierarchical agglomerative method, i.e. it begins with each station occupying an individual cluster. At each step, the closest pair of clusters are combined into a single cluster; this proceeds until all the stations are in a small number of clusters which are readily interpretable.

Squared Euclidean distance was used as a measure of dissimilarity between individual clusters. The distances between members of combined clusters may be evaluated as the minimum, average or maximum distances between individual members of the clusters being combined. These methods are referred to as single linkage, average linkage or complete linkage.

The spatial distribution of station groups (i.e. water quality zonation) derived using complete linkage is shown in Figures 3.20 and 3.21. This clearly shows three groups of
fig. 3.20

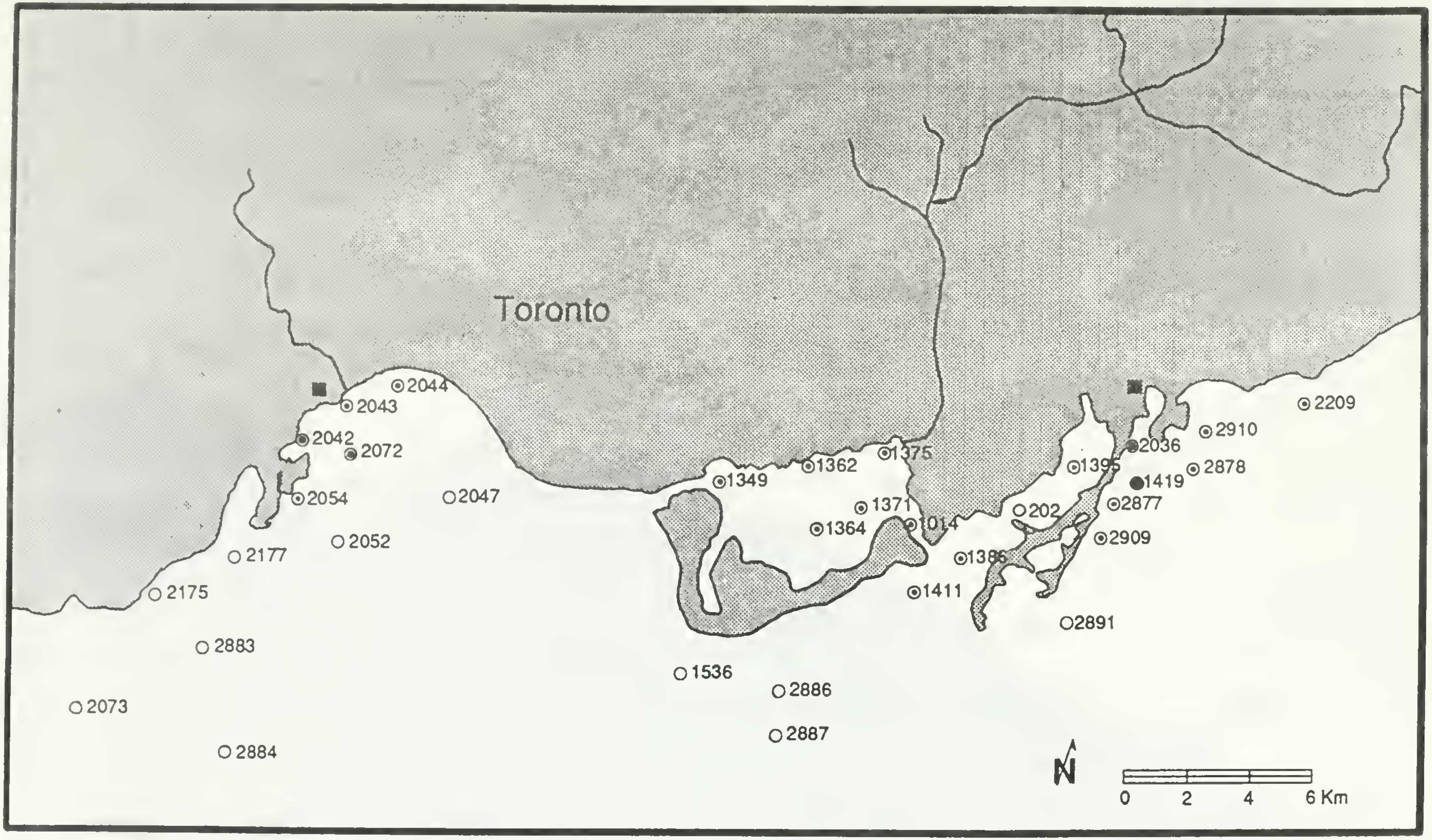


FIGURE 3.20
Water Quality Zones
in the Central Toronto Waterfront

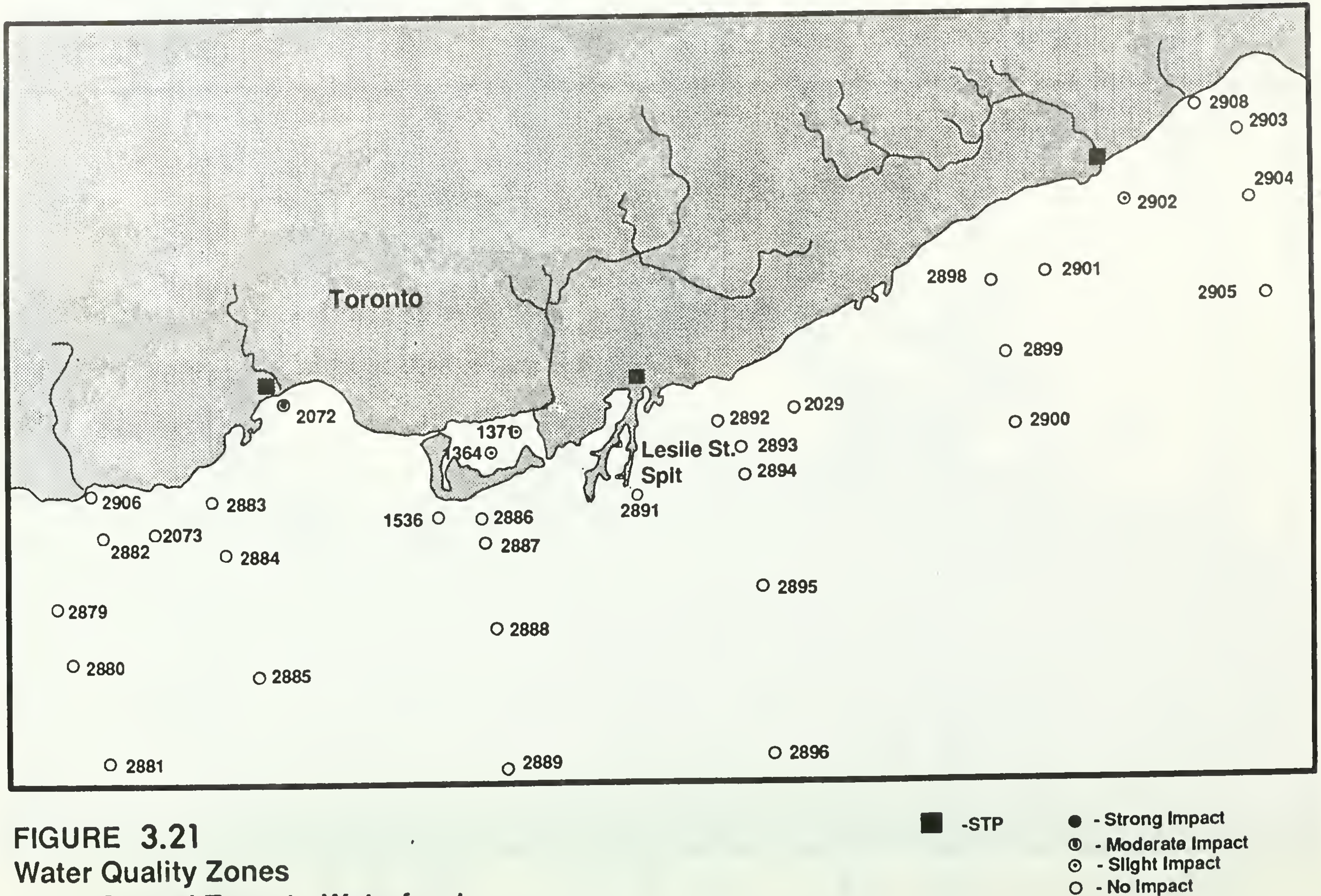


FIGURE 3.21
Water Quality Zones
in the Central Toronto Waterfront

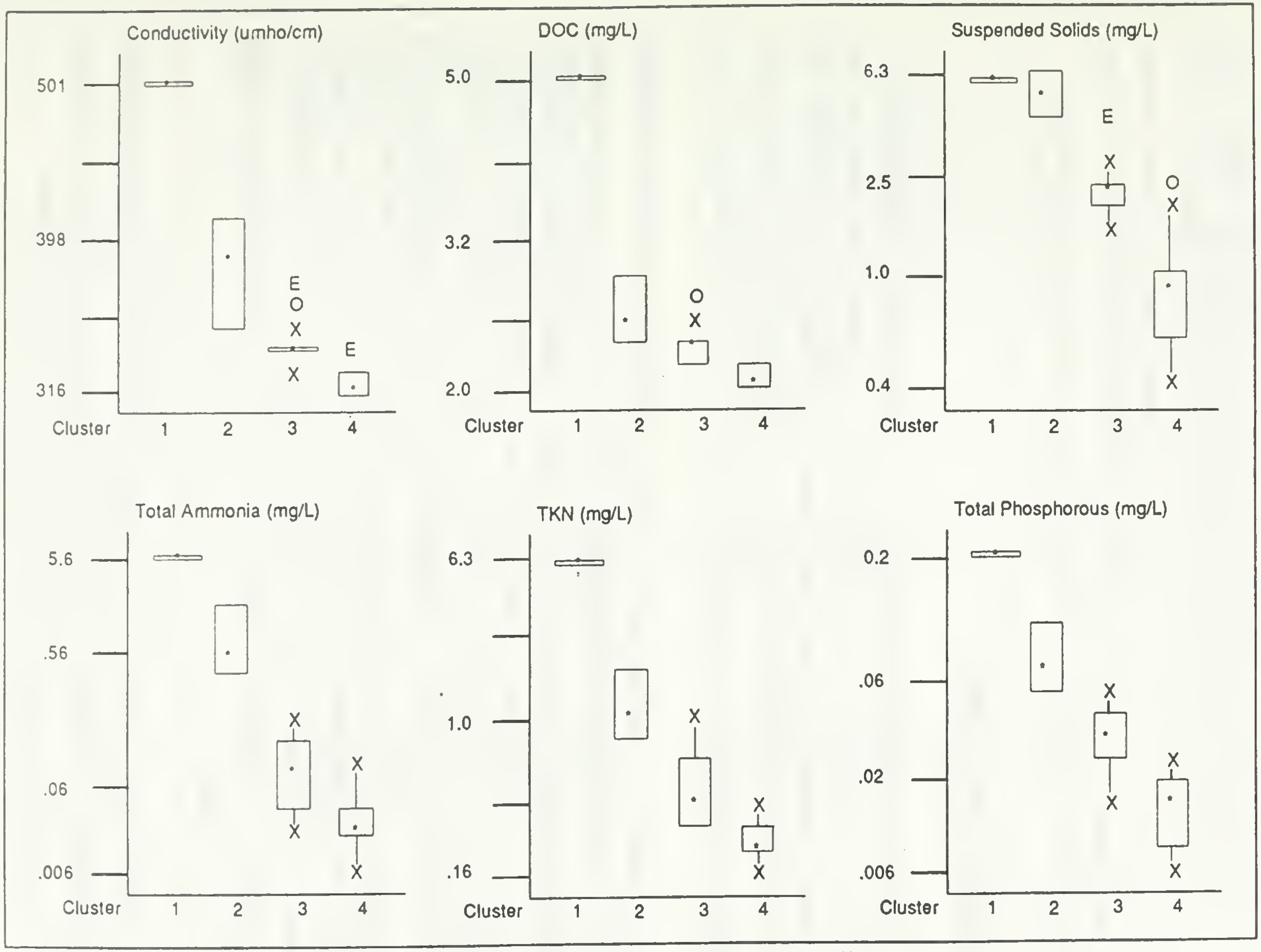


FIGURE 3.22
Log Scale Box Plots of Chemical Parameters in Water Quality Zones

Key

- • Median
- 25th,75th Percentiles
- X High/Low (Excluding Outliers and Extremes)
- O Outlier(Deviation >1.5 Interquartile Ranges)
- E Extreme (Deviation >2.5 Interquartile Ranges)

stations associated with known point sources. The Main STP outfall (Cluster 1) is quite distinct in terms of water quality. Other sources of moderate impact are represented by Cluster 2 (e.g. Humber Bay STP outfall). A zone of lesser impact (Cluster 3) is found beyond these moderate impact zones and in association with the Don River, Toronto Harbour and Rouge River. Cluster 4 represents relatively unimpacted stations. Box plots summarizing the water quality characteristics of each zone are shown in Figure 3.22.

3.3.2 <u>Ultra-Trace Organic Results</u>

The use of the APLE sampler during the three 1987 sampling periods represents the first comprehensive analysis of the concentrations of PBCs, organochlorine pesticides and chlorobenzenes undertaken in the Toronto Waterfront. Details of the sampling and analytical procedures are summarized in Section 2.0 and references cited therein; spatial distributions were obtained for a total of 25 contaminants and 64 PCB congeners.

Spatial distribution for all contaminants found are plotted by Halfon (1989); data are also found in the reports of Eli-Eco (1987) and Zenon (1987). Average concentrations of the organochlorine contaminants and total PCBs are given in Table 3.21 for each of the three survey periods. The data shown in Table 3.21 indicate that few contaminants are present in relatively high concentrations (>1 ng/L). Such contaminants include the dichlorobenzenes (DCB), α-BHC, γ-BHC (lindane) and, in October, total PCBs in 23 of 30 samples collected. This is most significant for total PCBs for which the PWQO is 1 ng/L. Levels of 1,2,4-trichlorobenzene (TCB), 1,2,3-TCB, and 1,2,3,4-tetrachloro-benzene (TeCB) were between 0.1 and 1 ng/L. Other contaminants averaged below 0.1 ng/L; however, as a large number of potentially toxic substances are present, they all are taken into account during the impact analysis.

Halfon (1989) classified the 26 stations according to a non-para- metric ranking procedure (Halfon and Reggiani, 1986) based on a vector approach method in which pairs of samples are compared according to the relative concentrations of all organochlorines

TABLE 3.21: AVERAGE CONCENTRATIONS (ng/L) OF ULTRA-TRACE ORGANIC CONTAMINANTS

Toronto Waterfront, 1987

Chlorobenzenes	June	August	October
1,3-dichlorobenzene	1.2	0.46	0.25
1,4-dichlorobenzene	6.3	9.4	0.0
1,2-dichlorobenzene	1.7	0.47	1.2
1,3,5-trichlorobenzene	0.016	0.022	0.028
1,2,4-trichlorobenzene	0.54	0.19	0.29
1,2,3-trichlorobenzene	0.13	0.030	0.044
1,2,3,5-tetrachlorobenzene	0.010	0.005	0.0
1,2,4,5-tetrachlorobenzene	0.048	0.053	0.057
1,2,3,4-tetrachlorobenzene	0.14	0.076	0.067
pentachlorobenzene	0.031	0.036	0.034
hexachlorobenzene	0.052	0.062	0.074
Organochlorine pesticides			
Hexachloroethane	0.017	0.030	0.009
Hexachlorobutadiene	0.006	0.010	0.0
2,4,5-trichlorotoluene	0.006	0.001	0.003
2,3,6-trichlorotoluene	0.0	0.002	0.0
Pentachlorotoluene	0.031	0.019	0.017
α-BHC	4.2	4.7	2.5
γ-BHC (Lindane)	1.1	1.0	0.58
Octachlorostyrene	0.008	0.0	0.005
γ-chlordane	0.010	0.009	0.030
pp'-DDE	0.030	0.021	0.035
pp'-DDD	0.015	0.012	0.028
pp'-DDT	0.0	0.0005	0.004
Mirex	0.0	0.0004	0.021
Total PCBs	0.58	0.82	2.5

and total PCBs. All possible pairs are intercompared, inconsistencies noted, and similarly behaving samples are grouped together. The result of the ranking procedures can be displayed as a Hasse diagram in which the most contaminated stations are located at the top (e.g. Figure 3.23) and then as a contour map showing areas where most contaminants are found (Figures 3.24 - 3.26 for the three cruise periods). These three maps show the combined plumes of 25 contaminants, thereby representing the co-occurrence of contaminants in any given area. It should be noted that the numerical values on these maps are only relative in nature; thus, they do not translate to any quantitative risk for exposure.

In June 1987 two impact zones were found: one on the western side of the waterfront near Humber Bay and one near the Lakeview STP (Figure 3.24; rankings >4). The eastern and offshore areas are much cleaner (rankings <2); as the water temperature was found to be lower in this area it probably represents dilution of contaminants by cleaner cooler hypolimnetic waters.

In July-August 1987 (Figure 3.25), the contaminant distribution was similar except that the plume from the Main STP area was shifted towards the Eastern beaches. Impacted zones also occur in the east off Scarborough (Highland Creek STP) and at one station offshore.

In October 1987 (Figure 3.26), the impacted areas were again similar. Off the Eastern beaches, the impact of local sources is reduced by dilution with hypolimnetic waters.

Positive identification of local sources of these contaminants is difficult as the concentration of most contaminants are relatively low and uniform. An exception was 1,4-dichlorobenzene (Figure 3.27), which showed an obvious source in Humber Bay during the June and August cruises. Local sources were also evident for 1,2-dichlorobenzenes and total PCBs. Several other chlorinated benzenes, including hexachlorobenzene, showed a general increase at the stations closest to shore. While this suggests multiple sources in the Toronto area, definite sources were not pinpointed.

Figure 3.23: Hasse diagram showing sample ranking of Toronto Waterfront sites. Station labels are defined by Halfon (1990). See Halfon (1990) for further details.

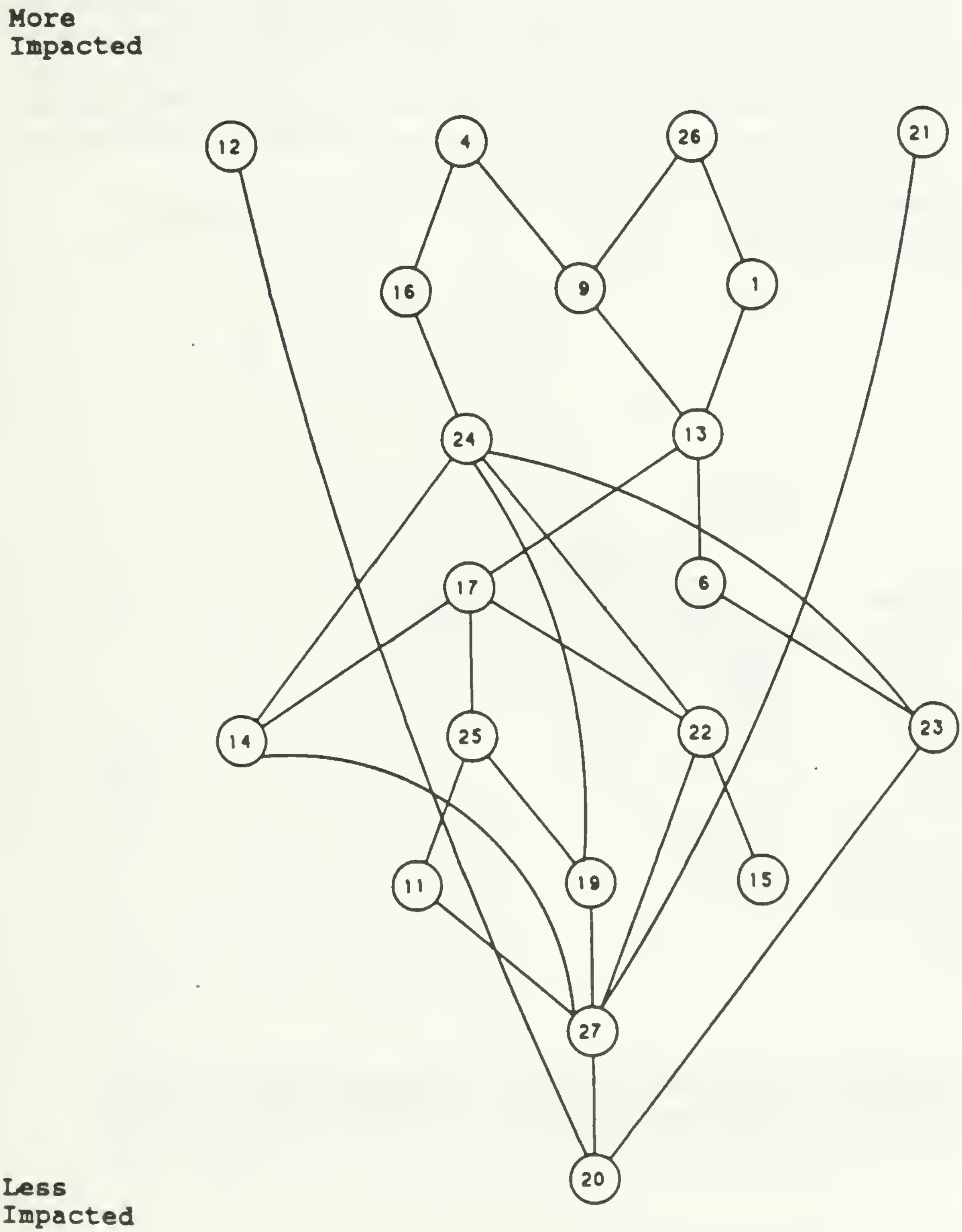


Figure 3.24: Idealized plumes which summarize the concentrations of 25 contaminants according to the results of the ranking analysis (Halfon, 1990), May-June 1987. Here stations on the same level in the Hasse diagram (Figure 3.23) are joined by a line. In May-June 1987, two polluted areas are seen, one located on the western zone of the Toronto Waterfront and one located near the Lakeview STP outfall. These stations are ranked at level 4 or higher. The offshore areas of the lake and the Scarborough Bluffs are ranked at level 2 or lower. In this area the water temperature is low and contaminants might have been diluted in cleaner, cooler hypolimnetic waters.

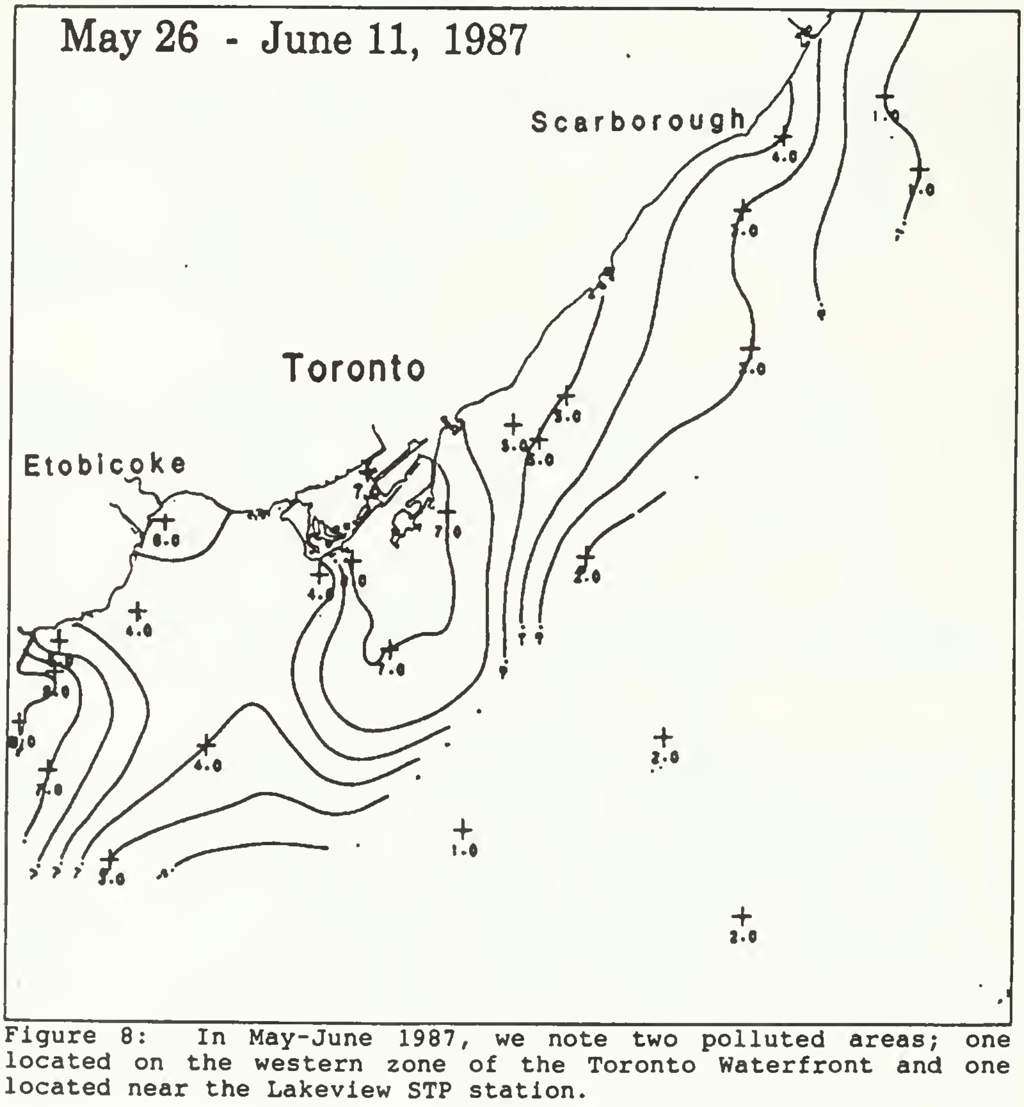


Figure 8: In May-June 1987, we note two polluted areas; one located on the western zone of the Toronto Waterfront and one located near the Lakeview STP station.

Figure 3.25: Idealized plumes which summarize the concentrations of 25 contaminants according to the results of the ranking analysis, July-August 1987. The pattern of pollution is similar to that observed in May-June. The impact plume off the harbour has shifted toward the Eastern Beaches while the plume in Humber Bay is practically unchanged. Zones impacted by a combination of toxic contaminants exist in the east off Scarborough and at one station offshore. Overall, the nearshore of the waterfront is more contaminated than the open waters.

Figure 9: In July-August, the pattern of pollution is similar to that one observed in May-June. The impact plume off the Toronto Harbour has shifted toward the eastern beaches while the plume in Humber Bay is practically unchanged.

Figure 3.26: Idealized plumes which summarize the concentrations of 25 contaminants according to the results of the ranking analysis, October 1987. The same areas identified in the previous two cruises are again observed. The only notable difference is an area offshore with rank 9. Off the Eastern Beaches, hypolimnetic waters lower the impact by toxic contaminants from shore.

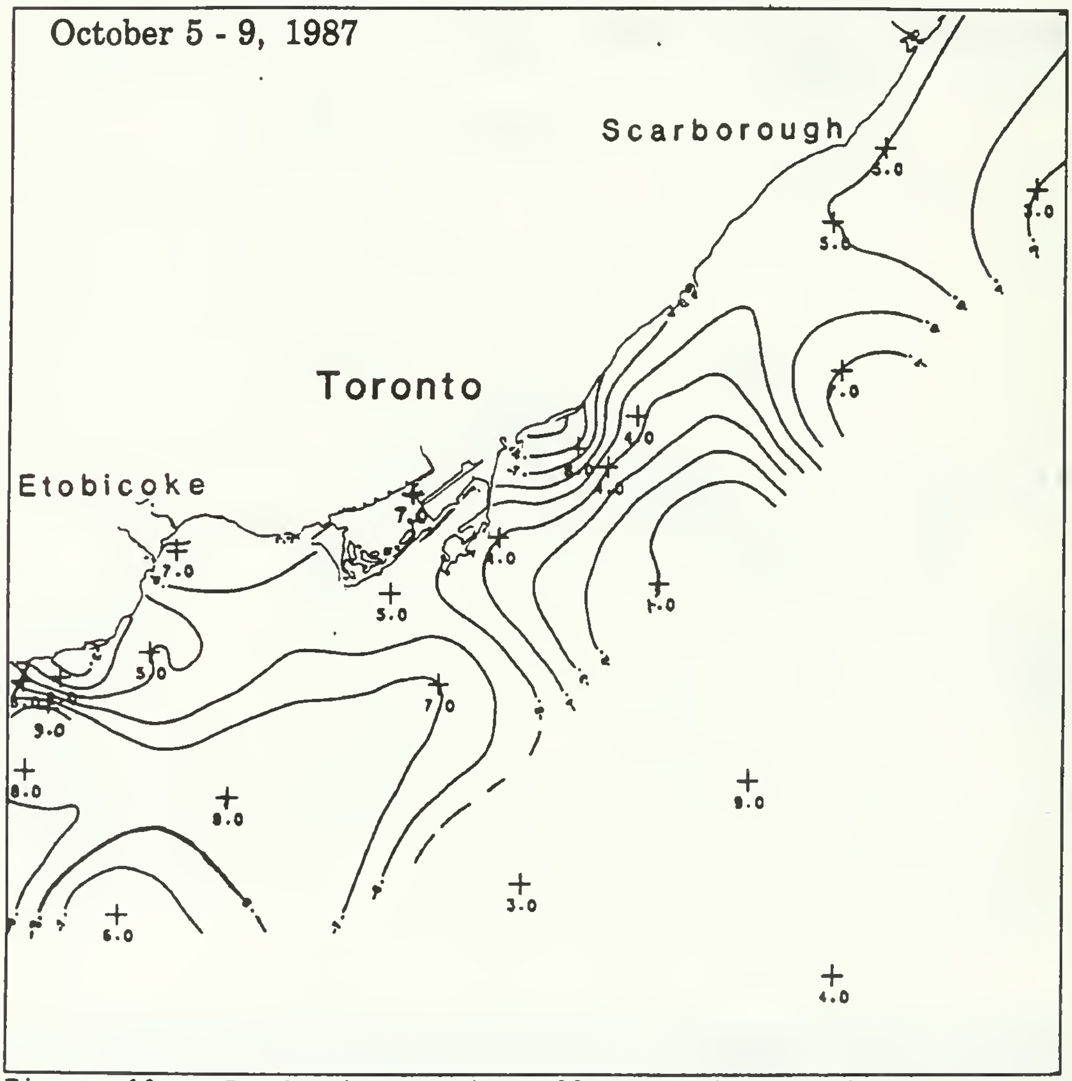
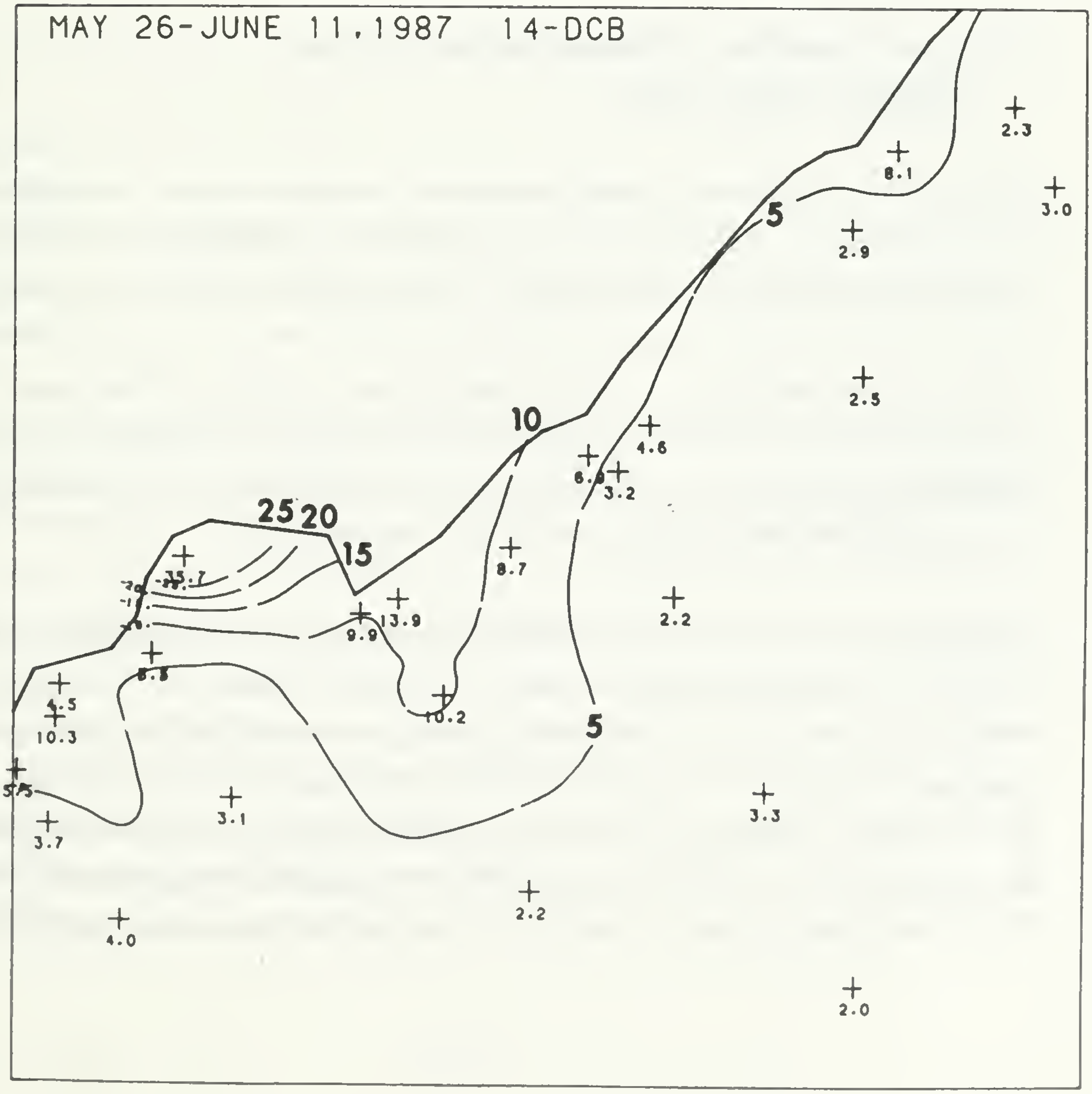


Figure 10: In October toxic pollutants impact the same ares identified in the June and August cruises.

FIGURE 3.27

Concentration of 1.4-dichlorobenzene (ng/L) as observed by ultra-trace methods, Toronto Waterfront, June 1987



As part of Lake Ontario, the Toronto Waterfront is exposed to whole-lake circulation patterns, which tend to replenish the water about every six to seven days. Thus, the baseline level of contaminants in the Toronto Waterfront is affected by remote sources as well as local sources. Only if all these sources were removed, would contaminant concentrations decrease rapidly to negligible levels, and rapidly only for water, suspended sediments and plankton. Levels in bottom sediments and the higher levels of the biotic food chain (e.g. fish) would decrease more slowly due to deposition (sediments) and bioaccumulation. These factors are being addressed in the fate modelling study.

3.3.3 Relative Importance of Various Sources to Toronto Waterfront Water Quality

Besides the Main STP, Lake Ontario in the Metro Toronto waterfront area is impacted by two other STPs within Metro Toronto: the Highland Creek STP and Humber STP, and six tributaries: the Etobicoke Creek, Mimico Creek, Humber River, Don River, Highland Creek and Rouge River. Numerous storm and combined sewers also discharge to the lake along the entire waterfront. As well, the atmosphere is another potential source of some contaminants such as PCBs. In addition, the Lakeview STP discharges to Lake Ontario in Mississauga, immediately west of the Metro Toronto limits. It is also considered here due to its potential for impacting upon the Toronto Waterfront.

Loadings from the four Toronto-area STPs discharging to Lake Ontario were calculated from MOE concentration data collected in 1987 and flows supplied by the plants (Table 3.22-3.23). A comparison of these loadings shows that the Main STP is by far the greatest contributor of conventionals (except for NO_2 + NO_3-N) and most heavy metals to the lake. In fact, for many conventionals, as well as chromium, copper, mercury and lead, the loading from the Main STP is similar to or greater than the combined loadings from the other three STPs. Most of this difference is due to the higher effluent flow rate at the Main STP (2.1

x Humber STP, 3.3 x Lakeview STP, and 4.7 x Highland Creek STP). For heavy metals, Lakeview STP is the greatest contributor of nickel, while Lakeview and Main contribute similar amounts of manganese.

Additional data provided to the MISA advisory committee (MOE, 1989) also indicates that in general, the Main STP is the highest contributor of metals of the nine STPs for which data were reported, although loadings for several metals from Ottawa (Green Creek) were somewhat higher. For most metals, mass balance data showed that the Main STP achieves above average removal efficiency; Highland Creek STP was also included in the study and showed above average removal efficiency for most metals.

For bacteria (Table 3.24), on an annual or summer (June and July-August) basis, Lakeview STP tends to be the greatest contributor and Highland Creek the least (except for P.aeruginosa); however, the day-to-day and month-to-month variability at most locations is high. At Lakeview, both scales of temporal variability are less than at other locations, with July-August bacterial loadings only slightly less than June or October. In fact, the bacterial loadings from the Main STP in October (after cessation of chlorination) are higher than at the other STPs.

Loadings of chlorobenzenes, organochlorine pesticides and PCBs as measured using 16-L samples (Sections 2.0, 3.1.1) are summarized in Table 3.25. Except for hexachloroethane, the Main STP is by far the greatest contributor of toxic organics, while the Humber STP is frequently next highest. While this may appear contradictory to the results of Section 3.3.2, where the most obvious source of toxic organics was found to be the Humber Bay area, it should be re-emphasized that the closest ultra-trace sampling locations to the Main STP (upon which section 3.32 was based) were 3 km from the outfall (due to limited water depth for the CCIW vessel during the ultra-trace sampling). Thus, the contaminants from the Main STP were far more diluted before being sampled, relative to those from the Humber STP. At any rate, the high concentration of 1,4-DCB observed in Humber Bay (Figure 3.27) is consistent with its loading of 330 g/day (Table 3.25). In addition, restricted

TABLE 3.22: LOADINGS OF CONVENTIONALS
ANNUAL MEANS, 1987 (10^3 kg/day)

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(a) Ammonia-N					
Main STP	20.0	6.5	8.9	34.6	47
Humber STP	5.8	1.8	3.7	10.9	48
Lakeview STP	2.1	1.7	0.06	4.8	49
Highland Creek STP	3.3	0.7	0.11	4.7	48
(b) Total Kjeldahl N					
Main STP	32.1	53.5	12.3	380.	45
Humber STP	7,0	2.3	4.3	14.	48
Lakeview STP	3.5	2.2	0.6	7.4	49
Highland Creek STP	4.5	0.8	2.6	6.3	48
(c) Nitrite + Nitrate-N					
Main STP	0.86	2.19	0.03	110.	48
Humber STP	0.15	0.37	0.01	2.5	47
Lakeview STP	2.65	1.34	0.16	6.6	49
Highland Creek STP	4.47	0.84	2.57	6.3	48
(d) Total Phosphorus					
Main STP	0.79	1.69	0.10	10.89	47
Humber STP	0.29	0.30	0.07	1.61	48
Lakeview STP	0.37	0.22	0.12	1.30	49
Highland Creek STP	0.29	0.29	0.07	1.28	48
(e) Suspended Solids					
Main STP	27.1	75.6	3.3	398.	47
Humber STP	6.1	6.6	1.8	37.	48
Lakeview STP	4.2	3.8	1.3	19.	49
Highland Creek STP	8.8	12.9	1.3	47.	47

(cont'd)....

TABLE 3.22 (cont'd): LOADINGS OF CONVENTIONALS
ANNUAL MEANS, 1987 (10^3 kg/day)

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(f) Total Dissolved Solids (Estimated as Conductivity x 0.65)					
Main STP	573.	142.	355.	961.	47
Humber STP	294.	19.	239.	328.	47
Lakeview STP	184.	20.	132.	218.	49
Highland Creek STP	145.	34.	99.	211.	47
(g) Total Filtered Residue (Measured Directly by Lab)					
Main STP	475.	122.	275.	734.	46
Humber STP	247.	26.	201.	334.	48
Lakeview STP	178.	21.	130.	222.	49
Highland Creek STP	117.	26.	78.	165.	47
(h) Chemical Oxygen Demand (as O)					
Main STP	87.2	81.0	33.9	442.	41
Humber STP	24.9	15.2	5.2	95.	42
Lakeview STP	24.3	12.0	10.5	64.	46
Highland Creek STP	20.4	14.5	8.1	70.	43
(i) Dissolved Organic Carbon					
Main STP	13.4	3.4	6.1	21.1	47
Humber STP	3.9	0.5	2.3	4.6	46
Lakeview STP	4.9	2.5	2.5	13.8	49
Highland Creek STP	2.3	0.4	0.6	3.0	47

**TABLE 3.23: LOADINGS OF HEAVY METALS
ANNUAL MEANS, 1987 (kg/day)**

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(a) Chromium					
Main STP	31.	48.	6.	270.	48
Humber STP	4.7	6.7	0.	36.	48
Lakeview STP	7.9	7.7	0.	31.	50
Highland Creek STP	3.3	4.4	0.	21.	48
(b) Copper					
Main STP	26.	46.	0.	238.	48
Humber STP	3.5	4.7	0.	23.	48
Lakeview STP	5.1	3.9	0.	16.	50
Highland Creek STP	7.9	11.2	1.	50.	48
(c) Iron					
Main STP	1.8×10^3	3.9×10^3	0.3×10^3	21×10^3	48
Humber STP	8.4×10^2	6.7×10^2	0.2×10^2	40×10^2	48
Lakeview STP	4.7×10^2	4.5×10^2	0.4×10^2	17×10^2	50
Highland Creek STP	4.8×10^2	5.8×10^2	0.9×10^2	27×10^2	48
(d) Mercury (g/day)					
Main STP	64.	122.	10.	653.	48
Humber STP	7.9	7.8	4.	45.	48
Lakeview STP	31.	33.	3.	130.	48
Highland Creek STP	7.3	10.5	2.	42.	48

(cont'd)...

TABLE 3.23 (cont'd): LOADINGS OF HEAVY METALS
ANNUAL MEANS, 1987 (kg/day)

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(a) Manganese					
Main STP	74.	28.	36.	156.	48
Humber STP	47.	13.	26.	79.	48
Lakeview STP	78.	38.	20.	148.	50
Highland Creek STP	61.	22.	30.	119.	48
(b) Nickel					
Main STP	34.	13.	17.	65.	48
Humber STP	25.	10.	4.	41.	48
Lakeview STP	60.	32.	19.	129.	48
Highland Creek STP	5.	2.	2.	12.	48
(c) Lead					
Main STP	12.	19.	0.	93.	48
Humber STP	4.0	4.3	0.	14.	48
Lakeview STP	3.0	2.4	0.	10.	50
Highland Creek STP	2.3	2.6	0.	11.	48
(d) Zinc					
Main STP	56.	110.	0.	550.	48
Humber STP	40.	26.	17.	153.	48
Lakeview STP	27.	15.	12.	83.	50
Highland Creek STP	14.	13.	4.	64.	48

TABLE 3.24: LOADINGS OF BACTERIA
ANNUAL MEANS, 1987 (organisms/day)

Parameter/Location	Geometric Mean	Std. dev. Lower Limit	Std. dev. Upper Limit	Min.	Max.	N
(a) Fecal Coliforms						
Main STP	2.8×10^{13}	8.7×10^{11}	9.5×10^{14}	2.0×10^{11}	1.7×10^{16}	46
Humber STP	3.2×10^{13}	6.4×10^{11}	1.5×10^{15}	$<4.5\times10^{10}$	5.6×10^{16}	45
Lakeview STP	1.1×10^{14}	3.3×10^{13}	3.4×10^{14}	7.4×10^{12}	8.5×10^{14}	46
Highland Creek STP	2.1×10^{13}	3.0×10^{12}	1.5×10^{14}	7.8×10^{11}	1.1×10^{15}	46
(b) E.coli						
Main STP	2.0×10^{13}	5.3×10^{11}	7.7×10^{14}	1.7×10^{11}	1.5×10^{16}	46
Humber STP	2.3×10^{13}	4.0×10^{11}	1.3×10^{15}	2.0×10^{10}	4.3×10^{16}	45
Lakeview STP	7.8×10^{13}	2.2×10^{13}	2.8×10^{14}	7.0×10^{12}	7.3×10^{14}	46
Highland Creek STP	1.8×10^{13}	2.4×10^{12}	1.3×10^{14}	5.6×10^{11}	1.0×10^{15}	46
(c) Fecal Streptococci						
Main STP	1.1×10^{13}	7.6×10^{11}	1.8×10^{14}	4.5×10^{10}	9.8×10^{14}	46
Humber STP	1.3×10^{13}	1.4×10^{12}	1.2×10^{14}	3.8×10^{10}	3.0×10^{15}	45
Lakeview STP	1.8×10^{13}	3.8×10^{12}	8.7×10^{13}	1.9×10^{12}	4.0×10^{14}	46
Highland Creek STP	5.1×10^{12}	1.6×10^{12}	1.7×10^{13}	1.7×10^{11}	5.2×10^{13}	45
(d) Pseudomonas aeruginosa						
Main STP	5.0×10^{11}	4.3×10^{10}	5.8×10^{12}	2.4×10^{10}	6.0×10^{13}	46
Humber STP	1.4×10^{12}	7.1×10^{10}	2.8×10^{13}	$<8.7\times10^{9}$	3.2×10^{14}	45
Lakeview STP	1.4×10^{12}	4.5×10^{11}	4.3×10^{12}	1.8×10^{11}	1.9×10^{13}	46
Highland Creek STP	7.4×10^{11}	1.8×10^{11}	3.1×10^{12}	1.8×10^{10}	7.0×10^{12}	46

TABLE 3.25: LOADINGS OF ULTRA-TRACE ORGANIC COMPOUNDS*
ANNUAL MEANS, 1987 (g/day)

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(a) 1,3-dichlorobenzene					
Main STP	78.	38.	25.	155.	10
Humber STP	25.	21.	6.	74.	9
Lakeview STP	5.4	4.1	0.	12.7	10
Highland Creek STP	2.4	2.2	0.	7.3	10
(b) 1,4-dichlorobenzene					
Main STP	630.	260.	100.	990.	10
Humber STP	330.	120.	150.	500.	9
Lakeview STP	130.	47.	84.	230.	10
Highland Creek STP	110.	270.	36.	140.	10
(c) 1,2-dichlorobenzene					
Main STP	280.	130.	63.	480.	10
Humber STP	95.	53.	24.	180.	9
Lakeview STP	44.	22.	16.	85.	10
Highland Creek STP	8.3	4.4	2.9	18.	10
(d) 1,3,5-trichlorobenzene					
Main STP	2.5	2.1	0.4	7.4	10
Humber STP	0.34	0.12	0.17	0.52	9
Lakeview STP	0.13	0.07	0.05	0.23	10
Highland Creek STP	0.05	0.05	0.	0.17	10
(e) 1,2,4-trichlorobenzene					
Main STP	116.	118.	15.	350.	10
Humber STP	6.3	1.6	4.4	9.8	9
Lakeview STP	8.3	16.9	1.4	56.	10
Highland Creek STP	1.2	0.03	0.6	1.7	10
(f) 1,2,3-trichlorobenzene					
Main STP	54.	79.	6.1	210.	10
Humber STP	0.96	0.25	0.50	1.44	9
Lakeview STP	0.50	0.28	0.22	1.13	10
Highland Creek STP	0.20	0.07	0.09	0.28	10

Note * - data based on large-volume (16L) samples.

(cont'd)...

TABLE 3.25 (cont'd): **LOADINGS OF ULTRA-TRACE ORGANIC COMPOUNDS ANNUAL MEANS, 1987 (g/day)**

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(g) 1,2,3,5-tetrachlorobenzene					
Main STP	9.2	15.8	0.1	42.	10
Humber STP	0.07	0.05	0.	0.15	9
Lakeview STP	0.	0.	0.	0.	10
Highland Creek STP	0.04	0.03	0.	0.08	9
(h) 1,2,4,5-tetrachlorobenzene					
Main STP	19.	15.	4.3	47.	10
Humber STP	0.35	0.17	0.08	0.59	9
Lakeview STP	0.08	0.04	0.	0.13	10
Highland Creek STP	0.26	0.11	0.10	0.44	10
(i) 1,2,3,4-tetrachlorobenzene					
Main STP	68.	101.	12.	271.	10
Humber STP	0.49	0.22	0.	0.68	9
Lakeview STP	0.82	0.04	0.	0.13	10
Highland Creek STP	0.28	0.17	0.06	0.57	10
(j) Pentachlorobenzene					
Main STP	6.9	5.	10.	16.	10
Humber STP	0.42	0.10	0.28	0.61	9
Lakeview STP	0.11	0.09	0.	0.32	10
Highland Creek STP	0.35	0.20	0.	0.69	10
(k) Hexachlorobenzene					
Main STP	4.1	6.1	0.	17.	10
Humber STP	0.18	0.04	0.09	0.22	9
Lakeview STP	0.15	0.11	0.	0.39	10
Highland Creek STP	0.17	0.17	0.	0.65	10
(l) Hexachloroethane					
Main STP	0.16	0.33	0.	1.1	10
Humber STP	1.03	1.37	0.	3.0	9
Lakeview STP	0.22	0.24	0.	0.60	10
Highland Creek STP	0.16	0.21	0.	0.61	10

(cont'd)

TABLE 3.25 (cont'd): **LOADINGS OF ULTRA-TRACE ORGANIC COMPOUNDS ANNUAL MEANS, 1987 (g/day)**

Parameter/Location	Mean	Std. Dev.	Min.	Max.	N
(m) α-BHC					
Main STP	1.3	0.8	0.	2.5	10
Humber STP	1.0	0.3	0.6	1.4	9
Lakeview STP	0.44	0.33	0.	0.90	10
Highland Creek STP	0.24	0.17	0.	0.49	10
(n) γ-BHC					
Main STP	21.	17.	0.	50.	10
Humber STP	15.	12.	0.	36.	9
Lakeview STP	11.	10.	0.	28.	10
Highland Creek STP	3.0	2.8	0.	8.5	10
(o) γ-chlordane					
Main STP	0.34	0.18	0.	0.67	10
Humber STP	0.08	0.06	0.	0.14	9
Lakeview STP	0.15	0.17	0.	0.49	10
Highland Creek STP	0.04	0.07	0.	0.24	10
(p) α-chlordane					
Main STP	0.43	0.42	0.	1.39	10
Humber STP	0.15	0.10	0.	0.29	9
Lakeview STP	0.11	0.15	0.	0.51	10
Highland Creek STP	0.05	0.42	0.	0.15	10
(q) Total PCBs					
Main STP	16.8	10.3	4.7	40.	10
Humber STP	3.7	2.3	1.2	7.7	9
Lakeview STP	3.5	5.8	0.4	20.	10
Highland Creek STP	1.4	1.3	0.2	4.3	10

circulation in Humber Bay may lower the dilution rate of contaminants relative to the Main STP area. Loadings of several other chlorobenzenes from the Humber STP are also reflected in the observed concentrations at station 2072.

3.3.4 Interparameter Correlations

Interparameter correlations within the receiving water are shown in Table 3.26. The best general surrogate for metals appears to be conductivity, although suspended solids, DOC and ammonia were also correlated with the same metals (Cr, Cu, Fe, Mn, Ni, Zn). No surrogates were found for Cd, Hg or Pb.

Of the organic parameters measured at conventional detection levels, only lindane (γ-BHC) and α-BHC were detected in receiving water with sufficient frequency to develop meaningful correlations. DOC provides the best general predictor of these two contaminants ($r =$ 0.89 and 0.48 for γ-BHC and α-BHC, respectively). However, conductivity, COD, ammonia and phosphorus were also correlated.

Correlation coefficients between surrogate parameters and ultra-trace (APLE) organics were also computed within the receiving water. However, as the APLE samples were not collected at the same time as the conventionals (because the APLE samples were collected by the CCIW survey vessels), it was necessary to use seasonal (June, July-August or October) mean values for conventionals at each station. Therefore, these correlations must be interpreted with caution. A subset file containing data for all survey dates only at the stations from which APLE samples were collected was prepared, and the requisite monthly means calculated using the same parameters as used in the STP effluent calculations (Section 3.1.4(b)) plus turbidity. The same procedures as described in that section was used to transform all data and produce correlations. The resulting correlations are shown in Table 3.27 (a-c) for each of the three survey periods.

TABLE 3.26: **INTERPARAMETER CORRELATIONS IN TORONTO WATERFRONT 1987**

	Cadmium	Chromium	Copper	Iron	Mercury	Manganese	Nickel	Lead	Zinc	α-BHC	β-BHC	-BHC
Conductivity (umhos/cm)	0.0920 (26)	0.1530* (425)	0.5021* (396)	0.5568* (473)	0.0459 (127)	0.7901* (492)	0.5852* (292)	-0.0448 (95)	0.3862* (258)	0.3035 (48)	0.2482 (91)	0.8030* (411)
DOC (mg/L)	-0.0266 (26)	0.1951* (427)	0.4877* (399)	0.5295* (476)	0.0679 (131)	0.7030* (497)	0.5320* (293)	-0.0532 (96)	0.3328* (258)	0.4827* (51)	0.2698 (9)	0.8896* (43)
COD (mg/L)	0.1228 (23)	-0.0191 (414)	0.2609* (392)	0.2836* (461)	0.0803 (129)	0.4138* (482)	0.3189* (292)	0.0125 (96)	0.0533 (247)	0.5829* (51)	0.4215 (9)	0.5449* (43)
pH	0.0846 (6)	-0.1268 (158)	-0.2342* (117)	-0.3928* (158)	-0.4617* (43)	-0.5459* (158)	-0.5610* (158)	-0.1701 (17)	-0.1788 (86)	-0.1764 (10)	- (0)	-0.5631 (8)
Suspended Solids (mg/L)	-0.1735 (26)	0.2078* (426)	0.5154* (398)	0.7188* (475)	0.0161 (131)	0.4908* (496)	0.2180* (293)	0.0107 (96)	0.4249* (257)	-0.11896 (51)	0.3394 (9)	0.1106 (43)
Ammonia (mg/L)	-0.0752 (26)	0.1456* (421)	0.4981* (390)	0.4846* (467)	0.0552 (131)	0.5511* (486)	0.5091* (292)	-0.0892 (96)	0.3365* (251)	0.3334 (49)	0.2179 (8)	0.8619* (41)
Phosphorus (mg/L)	-0.1599 (26)	0.0997 (431)	0.5086* (403)	0.6202* (480)	0.0580 (132)	0.5772* (499)	0.4121* (296)	0.0024 (97)	0.4480* (259)	0.3443* (51)	0.4519 (9)	0.6110* (43)

(n) indicates number of samples with paired measurements above detection limits contributing to the correlation coefficient.
* indicates statistical significance based on one-tailed test ($p<0.01$).

Note: With log transformation prior to computation, coefficients change slightly and a few marginally significant coefficients become insignificant at the stated probability, while a few insignificant coefficients become significant. The superiority of conductivity and suspended solids as metal unchanged.

Table 3.27(a): ***Correlations between conventional and ultra-trace organic parameters Toronto Waterfront, June 1987***

Correlations:	***DCB13***	***DCB14***	***DCB12***	***TCB135***	***TCB124***	***TCB123***	***TECB1235***	***TECB1245***	***TECB1234***	***QCB***	***HCB***	***HCE***	***ABHC***	***LINDANE***	***GCHLOR***	***PPDDE***	***PCB***
NNOTFR	.2141	.0931	.1687	2657	.2488	-.4130	.1699	.1151	.2123	.2385	.3414	-.0256	.0342	.1774	.3380	.4842	-.1059
	P= .283	P= .644	P= .400	P= .180	P= .211	P= .032	P= .397	P= .568	P= 288	P= .231	P= .081	P= .899	P= .866	P= .376	P= .085	P= .010	P= .606
NNTKUR	.3467	.8673	.8655	.5944	.6762	.3387	4664	.5611	.4804	.6325	.3455	.6979	-.0758	.6395	.6123	1169	4462
	P= .076	P= .000	P= .000	P= .001	P= .000	P= .084	P= .014	P= .002	P= .011	P= .000	P= .078	P= .000	P= .707	P= .000	P= .001	P= .561	P= .022
PPUT	.2232	.7983	.7870	.4344	.6635	.3937	.4013	.5763	.4420	.6349	.3018	6572	.0480	.6434	.4775	-.1214	6294
	P= .263	P= .000	P= .000	P= .024	P= .000	P= .042	P= .038	P= .002	P= .021	P= .000	P= .126	P= .000	P= .812	P= .000	P= .012	P= .546	P= 001
PH	-.2437	-.6844	-.6978	-.4838	-.5843	-.5497	-.3473	-.6653	-.5887	-.5967	-.0601	-.4974	.0572	-.4459	-.2194	-.1578	.0531
	P= .221	P= .000	P= .000	P= .011	P= .001	P= .003	P= .076	P= .000	P= .001	P= .001	P= .766	P= .008	P= .777	P= .020	P= .271	P= .432	P= .797
COD	.3296	.2644	.4001	.2156	.3674	.4179	.5601	.0558	.3227	.4294	.0298	.3386	-.2214	.0749	.3040	-.0553	.1703
	P= .093	P= .183	P= .039	P= .280	P= .059	P= .030	P= .002	P= .782	P= .101	P= .025	P= .883	P= .084	P= .267	P= .710	P= .123	P= .784	P= 406
COND	.4513	.5521	.6376	.4013	.5223	.2341	.4944	.3064	.3265	.4152	.2556	.6429	.1150	.3243	.5541	.0785	.3072
	P= .018	P= .003	P= .000	P= .038	P= .005	P= .240	P= .009	P= .120	P= .097	P= .031	P= .198	P= .000	P= .568	P= .099	P= .003	P= .697	P= .127
DOC	.1218	.4904	.3534	.4600	.0480	-.1788	.2316	.1192	-.0820	-.0028	.2321	.3916	-.1192	.2327	.4868	.1027	.3151
	P= .545	P= .009	P= .071	P= .016	P= .812	P= .372	P= 245	P= .554	P= .684	P= .989	P= .244	P= .043	P= .554	P= .243	P= .010	P= 610	P= 117
RSF	-.0127	.6230	.4213	4230	.1084	-.1318	.2101	.1706	-.0377	.0796	.2238	.4721	-.1246	4575	.4694	0579	.4413
	P= .950	P= .001	P= .029	P= .028	P= .590	P= .512	P= 293	P= .395	P= .852	P= .693	P= .262	P= .013	P= .536	P= .016	P= .013	P= .774	P= .024
RSP	1760	.1685	.1724	2938	.1373	-.1412	.1620	.0169	.1131	0673	.2776	.0487	-.2839	.0164	.2464	.4122	-.1392
	P= .380	P= .401	P= .390	P= .137	P= 495	P= .483	P= .419	P= .933	P= .574	P= .739	P= .161	P= .809	P= .151	P= .935	P= .215	P= 033	P= .498
TURB	2288	.4033	.3431	.3636	.1395	.0444	.2258	.0737	.1876	.1512	-.1329	.3682	-.3830	.2220	.2096	.3611	-.0955
	P= .251	P= .037	P= .080	P= .062	P= 488	P= .826	P= .257	P= .715	P= .349	P= .452	P= .509	P= .059	P= .049	P= .266	P= 294	P= .064	P= .643

Note: First number is correlation coefficient.

Number of observations = 27 (26 for PCB)
P= probability of random correlation
Organic parameters are as identified in Table 3.14

Table 3.27(b): *Correlations between conventional and ultra-trace organic parameters Toronto Waterfront, August 1987*

Correlations:	DCB13	DCB14	TCB135	TCB124	TCB123	TECB1245	TECB1234	OCB	HCB	HCE	ABHC	LINDANE	GCHLOR	PPDDE	PCB
NNOTFR	-.1751 P=.402	.0925 P=.660	.0587 P=.781	3649 P=.087	-.3357 P=.101	.0365 P=.862	.7257 P=.000	.5703 P=.003	.1644 P=.432	-.2576 P=.214	-.3488 P=.087	-.0060 P=.977	-.0033 P=.988	.2860 P=.166	1029 P=.625
NNTKUR	.0931 P=.658	.4755 P=.016	.0632 P=.764	4180 P=.047	-.2523 P=.224	-.1941 P=.352	.5436 P=.006	2555 P=.218	.3375 P=.099	.5190 P=.008	-.1813 P=.386	4836 P=.014	.0448 P=.832	.5704 P=.003	4694 P=.018
PPUT	.0896 P=.670	6042 P=.001	.0712 P=.735	5333 P=.009	-.2233 P=.283	-.0691 P=.743	.6881 P=.000	.4531 P=.023	.4089 P=.042	.5273 P=.007	-.1151 P=.584	.5640 P=.003	.0900 P=.669	6617 P=.000	5959 P=.002
PH	-.2809 P=.174	-.6268 P=.001	-.0927 P=.660	.4096 P=.052	.3042 P=.139	.0317 P=.880	-.2528 P=.233	-.1329 P=.526	-.2467 P=.235	-.8427 P=.000	.0759 P=.719	-.6525 P=.000	.1515 P=.470	-.3671 P=.071	.4591 P=.021
COD	-.1787 P=.393	-.5711 P=.003	-.1717 P=.412	.5182 P=.011	-.5053 P=.010	.3122 P=.129	-.3450 P=.099	-.1466 P=.484	-.4322 P=.031	-.3035 P=.140	-.4210 P=.036	-.4699 P=.018	-.5607 P=.004	-.4058 P=.044	-.1905 P=.362
COND	.1627 P=.437	6288 P=.001	.1836 P=.380	5917 P=.003	-.3210 P=.118	.0485 P=.818	.6059 P=.002	.4903 P=.013	.3585 P=.078	.6402 P=.001	-.2185 P=.294	.5406 P=.005	-.1505 P=.473	.4989 P=.011	.5617 P=.003
DOC	.2621 P=.206	6256 P=.001	.1237 P=.556	5637 P=.005	-.1069 P=.611	-.1541 P=.462	.4609 P=.023	2604 P=.209	.3770 P=.063	.7362 P=.000	-.1113 P=.596	.6214 P=.001	.0835 P=.691	.4938 P=.012	5545 P=.004
RSF	.1199 P=.568	.5931 P=.002	.1212 P=.564	6430 P=.001	-.0832 P=.693	-.2309 P=.267	.7535 P=.000	.4066 P=.044	.4738 P=.017	.5021 P=.011	-.1982 P=.342	.5209 P=.008	.1843 P=.378	.5200 P=.008	4576 P=.021
RSP	1698 P=.417	.5574 P=.004	-.0459 P=.827	.3558 P=.096	-.2233 P=.283	-.0303 P=.886	.5040 P=.012	.3976 P=.049	.3229 P=.115	4340 P=.030	.0046 P=.982	.5729 P=.003	.1213 P=.564	.6795 P=.000	.5847 P=.002
TURB	-.0257 P=.903	-.0763 P=.717	.2554 P=.218	.2384 P=.273	-.3702 P=.069	.3138 P=.127	-.1830 P=.392	0965 P=.646	0389 P=.854	.0212 P=.920	-.2371 P=.254	-.1982 P=.342	-.3355 P=.101	.0066 P=.975	.2464 P=.235

Note: First number is correlation coefficient.

Number of observations = 25 (23 for TCB123) (24 for TECB1234)
P = probability of random correlation
Organic parameters are as identified in Table 3.14

Table 3.27(c): *Correlations between conventional and ultra-trace organic parameters Toronto Waterfront, October 1987*

Correlations:	*DCB12*	*TCB135*	*TCB124*	*TCB123*	*TECB1245*	*TECB1234*	*OCB*	*HCB*	*HCE*	*ABHC*	*LINDANE*	*GCHLOR*	*PPDDE*	*PPDDD*	*PCB*
NNHTFR	.3575	.0009	.2313	.2820	-.1290	.0992	-.2171	-.1983	-.2205	-.2076	-.0674	-.0635	-.0250	-.1067	-.0836
	P= .079	P= .997	P= .266	P= .172	P= .539	P= .637	P= .297	P= .342	P= .290	P= .319	P= .749	P= .763	P= .906	P= .612	P= .691
NNOTFR	.2139	.3195	.0192	.3074	.1410	.4028	-.2062	-.3412	-.0618	-.2141	-.1199	-.0558	.0681	-.1508	-.2801
	P= .305	P= .120	P= .927	P= .135	P= .501	P= .046	P= .323	P= .095	P= .769	P= .304	P= .568	P= .791	P= .746	P= .472	P= .175
NNTKUR	.3955	.0564	.3077	.2776	-.0863	.1603	-.2404	-.2652	-.2190	-.1923	-.0548	-.0844	-.0452	-.1729	-.1165
	P= .050	P= .789	P= .135	P= .179	P= .682	P= .444	P= .247	P= .200	P= .293	P= .357	P= .795	P= .688	P= .830	P= .409	P= .579
PPUT	.4057	.2941	.3568	.4085	.0391	.1815	-.2218	-.3360	-.1075	-.1550	-.0682	.0827	-.0569	-.0392	-.1796
	P= .044	P= .154	P= .080	P= .043	P= .853	P= .385	P= .287	P= .101	P= .609	P= .459	P= .746	P= .694	P= .787	P= .852	P= .390
PH	-.3312	-.1179	-.4684	-.0838	.1591	.1522	-.1281	-.0667	.0008	-.0862	-.1627	-.2298	-.0678	-.2224	-.1448
	P= .106	P= .575	P= .018	P= .690	P= .447	P= .468	P= .542	P= .751	P= .997	P= .682	P= .437	P= .269	P= .747	P= .285	P= .490
COD	.5745	.2977	.3823	-.0427	-.1106	-.0278	-.0038	-.0837	.0320	.1090	.2415	.0363	.0427	.1732	-.0229
	P= .003	P= .148	P= .059	P= .839	P= .599	P= .895	P= .986	P= .691	P= .879	P= .604	P= .245	P= .863	P= .840	P= .408	P= .913
COND	.4191	.2216	.3900	.2990	.0079	.1240	-.1233	-.2320	-.0611	-.0356	.0489	.1488	-.0106	.0883	-.1262
	P= .037	P= .287	P= .054	P= .146	P= .970	P= .555	P= .557	P= .264	P= .772	P= .866	P= .816	P= .478	P= .960	P= .675	P= .548
DOC	.3751	.1882	.3908	.1050	-.2007	-.1201	-.0934	-.0986	-.0606	.0090	.0711	.0278	.0021	-.0020	.0033
	P= .065	P= .368	P= .053	P= .617	P= .336	P= .567	P= .657	P= .639	P= .774	P= .966	P= .735	P= .895	P= .992	P= .993	P= .988
RSF	.4212	.2222	.3991	.2799	-.0140	.1069	-.1201	-.2170	-.0447	-.0297	.0507	.1451	.0044	.0848	-.1254
	P= .036	P= .286	P= .048	P= .175	P= .947	P= .611	P= .568	P= .297	P= .832	P= .888	P= .810	P= .489	P= .984	P= .687	P= .550
RSP	.3180	-.0817	.2856	.2273	.0129	.2445	-.2425	-.3321	-.1270	-.0924	-.1214	.0855	.0503	-.1073	-.1078
	P= .121	P= .698	P= .166	P= .275	P= .951	P= .239	P= .243	P= .105	P= .545	P= .661	P= .563	P= .685	P= .811	P= .610	P= .608
TURB	.3871	-.1375	.3071	.2419	.0306	.2657	-.2320	-.2775	-.1470	-.1451	-.0535	.0550	-.0108	-.1170	.0057
	P= .056	P= .512	P= .135	P= .244	P= .885	P= .199	P= .265	P= .179	P= .483	P= .489	P= .799	P= .794	P= .959	P= .578	P= .978

Note: First number is correlation coefficient

Number of observations = 25
P= probability of random correlation
Organic parameters are as identified in Table 3.14

In June and August a large number of significant ($P<0.05$) correlations are found, while in October very few significant correlations were found. In June, the best overall surrogates appeared to be total Kjeldahl nitrogen and total phosphorus, each of which had a large number of highly significant ($P<0.01$) correlations. Scatterplots of typical correlations are shown in Figures 3.28-3.29. In all these figures, the highest TKN or total P concentration was found at station 2072 (Humber STP); this station also represented one of the highest concentrations for most parameters and an average value for PCB. The highest PCB concentrations during this survey period was found at the far west end of the study area and represent "outliers" on Figure 3.26; the source of these PCBs is unknown and appeared to originate from outside the study area.

The June data (Table 3.27(a)) appear to suggest that pH and conductivity would be good surrogates for several parameters. However, examination of scatterplots indicated a very narrow range for these parameters at most stations, with the correlations entirely determined by high conductivity and low pH at the Humber STP station only.

In August, total phosphorus again was a good surrogate for many of the organic parameters (Figure 3.29) but total Kjeldahl N was less successful. Conductivity, and suspended solids were useful predictors for some organics (Figure 3.29). High concentration of conventional and ultra-trace parameters were found at Stations 2072 (Humber STP), 1375 (inner harbour near Don River) and 2891 (3 km south of Main STP). The latter station especially is useful with respect to modelling and plume tracking.

In October, very few successful correlations were found, and no conventional parameter was capable of predicting ultra-trace organic contaminant concentrations (Table 3.27c). However, a large portion of the contaminants exhibited very low to non-detectable concentrations at most stations in October, and consequently no reasonable predictions can be made for that survey month.

Figure 3.28 a-b

Scatterplots of 1,2-dichlorobenzene and 1,2,4-trichlorobenzene with total Kjeldahl nitrogen Toronto Waterfront, June 1987.

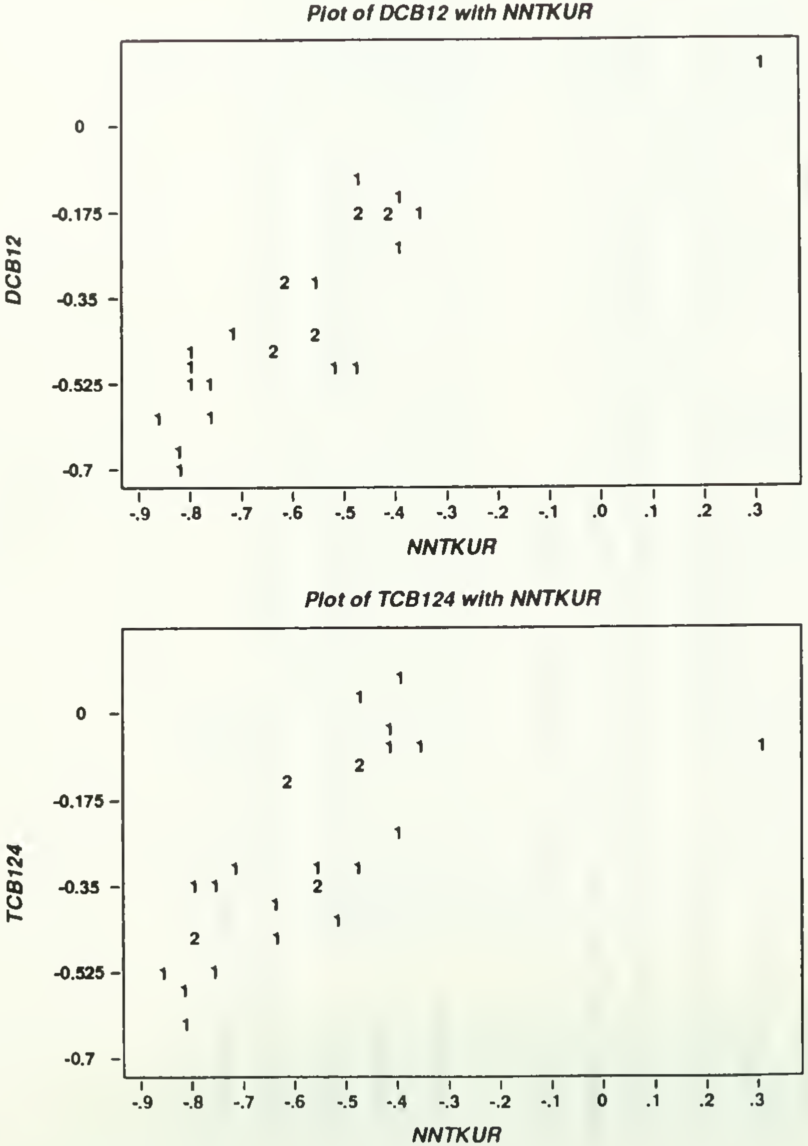


Figure 3.28 c-d

Scatterplots of pentachlorobenzene and total PCB's with total phosphorus Toronto Waterfront, June 1987.

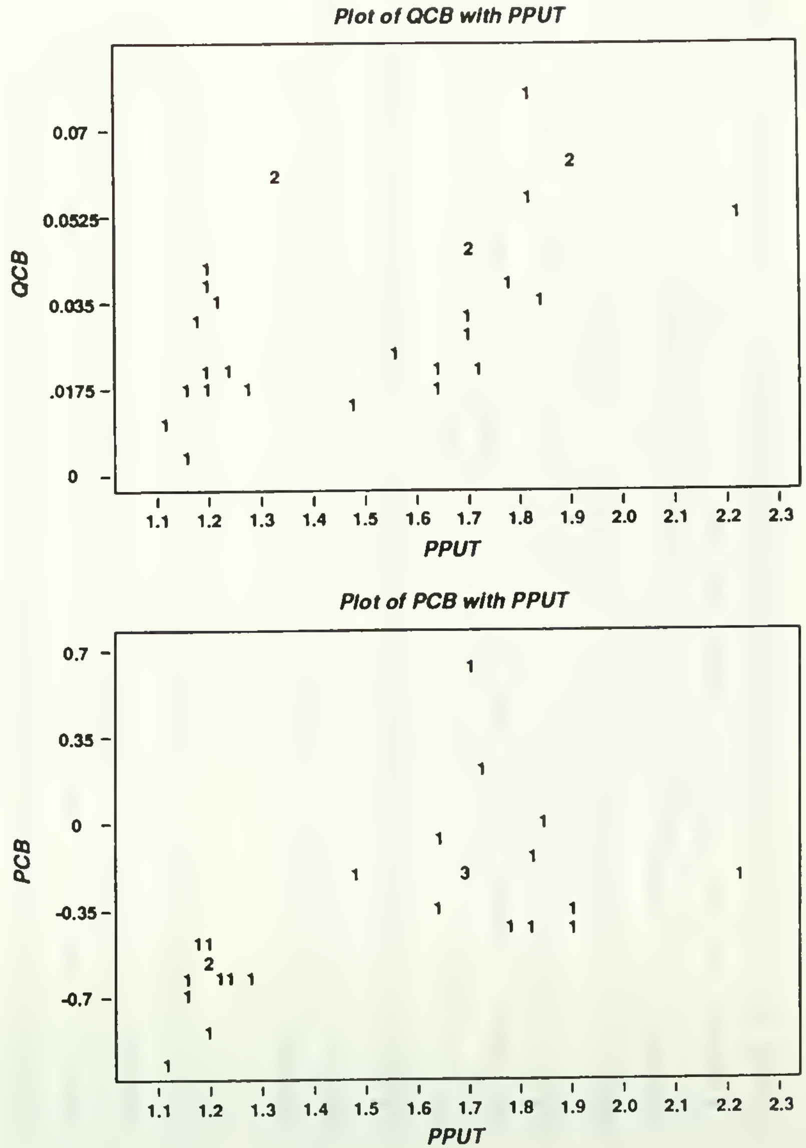


Figure 3.29 a-b

Scatterplots of 1,4-dichlorobenzene with a) total phosphorus and b) conductivity Toronto Waterfront, June-August 1987.

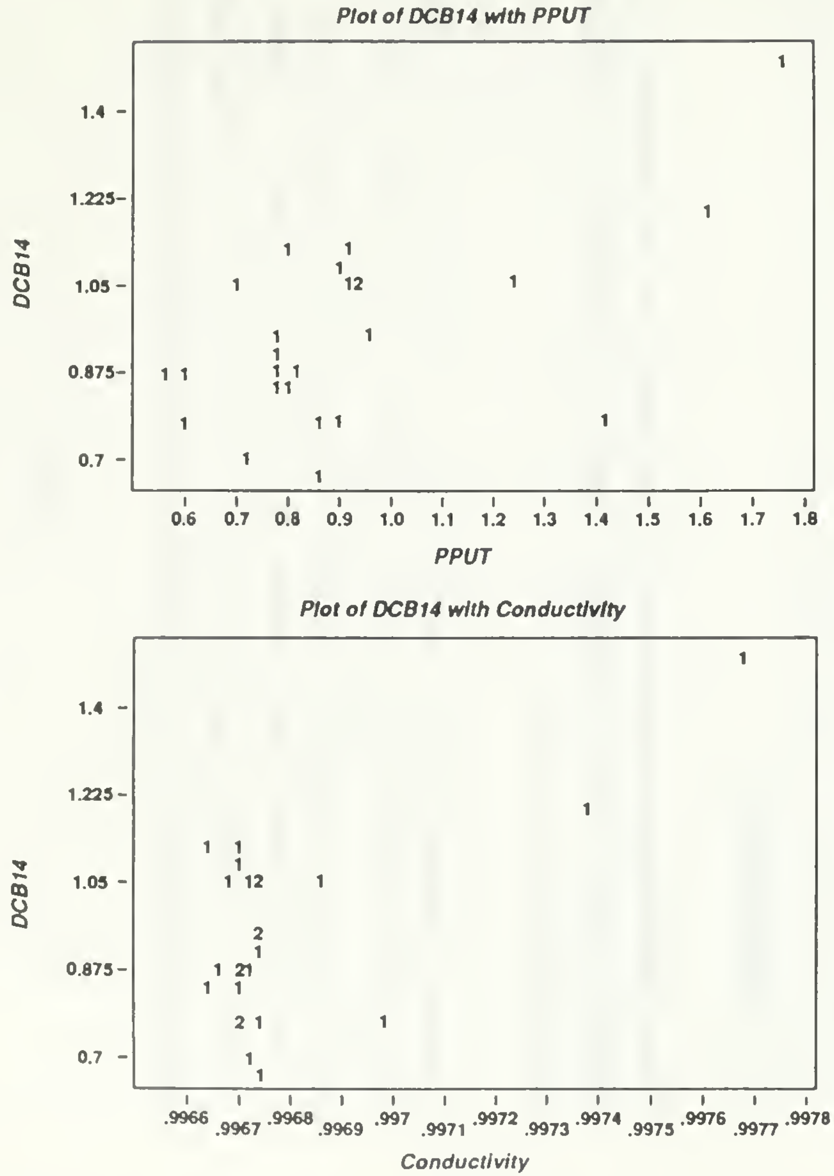
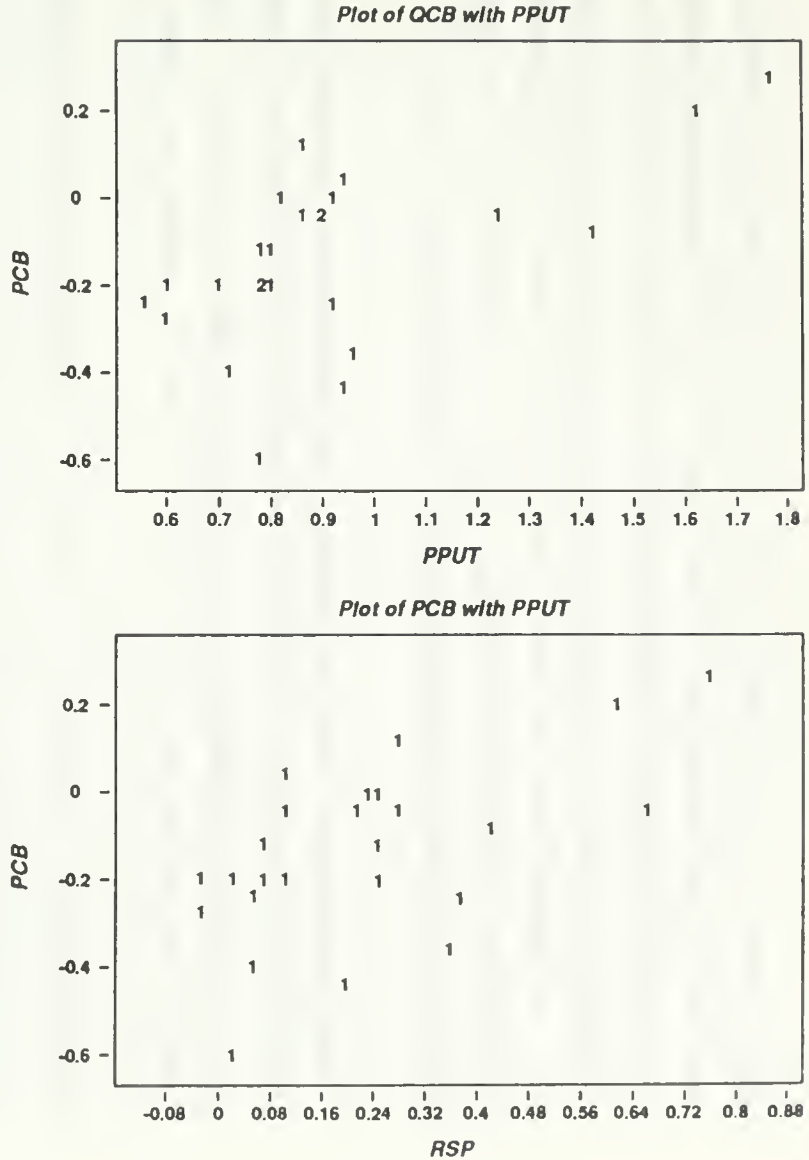


Figure 3.29 c-d

Scatterplots of total PCBs with a) total phosphorus and b) total suspended solids Toronto Waterfront, June-August 1987.



Halfon (1989) also correlated these organic parameters with temperature measured at the same time as sample collection. He found a positive correlation with many parameters in June, a negative correlation in July-August and no correlation in October. He was able to relate both correlations to sources at Humber Bay, which is similar to the results obtained here. His impacted zones also showed the effects of other sources including the Main STP. Both his work and that performed here suggest that similar transport mechanisms are important in determining the distribution of various contaminants.

Overall, considering all data obtained, total phosphorus appeared to be the best surrogate of many ultra-trace organics. However, the correlation patterns are time-dependent and must be established separately for each particular case to be studied. While more successful than the results for the Main STP effluent, the usefulness of these results is limited by the fact that most samples were obtained in the least impacted areas of the waterfront (cluster 4; section 3.3.1). The lack of stations close to the Main STP outfall was a serious drawback; further work should emphasize this area and other impacted zones in order to obtain a better range of values for both conventional and toxic parameters.

3.3.5 Temporal Trends

Only a limited comparison of seasonal trends is possible with the given data, by examining the cruise means of various parameters within individual clusters and at selected stations (1419, 1536, 2029).

In general, conductivity, COD, ammonia, TKN and phosphorus tend to decline on the waterfront from June through August or September, with an increase again in the fall. Similar declines in conductivity and nitrogen parameters have previously been observed (Poulton and Griffiths, 1986); however, the latter study showed an irregular seasonal variation in total phosphorus in the inner and outer harbours. In contrast, turbidity and suspended solids tend to increase slightly from June through August, declining thereafter.

At the Main STP outfall (station 1419), deviations from the general trend were often observed, either by exaggeration (e.g. turbidity, suspended solids), or by opposition (e.g. phosphorus). Variability was often greater at Station 1419, commensurate with the greater concentrations here, and with the known variability in discharge rates from the Main STP.

In comparison to 1986, free chlorine discharge was apparently lower in 1987 (annual means at Station 1419 were 1,018 ± 1,143 and 270 ± 271 μg/L, respectively; medians were 540 and 324 μg/L, respectively), although the number of sampling days was small in 1986 ($n = 4$). Ammonia and phosphorus concentrations at the outfall were similar between years. Metal concentrations were slightly higher in 1987 for iron, chromium, mercury, manganese and nickel but lower for zinc (Appendix 2). Only the manganese and nickel increases were statistically significant ($p<0.05$).

3.3.6 Comparison to Historical Data

Table 3.28 shows historical water quality data from the Toronto Waterfront General Water Quality 1976-1983 Report (Poulton and Griffiths, 1986) and Boyd (1988) for parameters of interest.

The spatial boundaries of the zones used in the 1986 report were calculated based upon the same parameters as in this report plus Secchi disk and Chla, which are both, on average, spatially invariant. The correspondence between the zones of this report and of Table 3.28 are roughly as follows:

TABLE 3.28: COMPARISON OF CURRENT AND HISTORICAL DATA BY ZONE

Parameter	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1976						
NH_3-N		0.08	0.13	0.26		0.56
Total P		0.031	0.040	0.066		0.10
Conductivity (umhos/cm)		350	360	430		510
Turbidity (FTU)		2.3	3.0	5.8		8.4
1977-1978						
NH_3-N	0.099	0.095	0.094	0.34	2.6	1.8
Total P	0.02	0.03	0.04	0.06	0.12	0.16
Conductivity (umhos/cm)	340	360	380	450	450	850
Turbidity (FTU)	0.94	1.8	2.1	3.7	2.1	14
June 1983						
Total P	0.018	0.024	0.027	0.039	0.054	0.19
Conductivity (umhos/cm)	350	351	370	420	370	960
Turbidity (FTU)	1.1	1.2	1.7	2.6	1.8	9.2
1985						
Total P	0.01	0.03	0.03	0.20	0.30	0.3
Conductivity	324	346	346	429	465	465
Turbidity (FTU)	2.1	5.7	5.7	5.3	7.5	7.5
1987						
NH_3-N	0.05	0.06	0.06	0.56	5.6	
Total P	0.01	0.04	0.04	0.06	0.2	
Conductivity (umhos/cm)	316	330	330	370	500	

Note: Units are mg/L unless otherwise stated.

Zones in Toronto Waterfront

This Report (Figure 3.23)	Water Quality Report
Strong Impact	Zone 5
Moderate Impact	Zone 4
Slight Impact	Zones 2 and 3
No Impact	Zone 1

However, both the stations sampled and the season of sampling have varied from year to year.

Available data suggest that conductivity has been generally decreasing over the past decade, but an opposite trend is seen in Zone 5 in the vicinity of the Main STP (Station 1419) from 1983 through 1987. Similarly, ammonia has been generally decreasing in concentration, but has been increasing in Zone 4 (Don River mouth) and Zone 5 from 1978 through 1987. Turbidity was apparently decreasing from 1976 through 1983, but increased again in 1985.

Total phosphorus has been generally increasing since 1983, but this trend is much stronger in Zones 4 and 5, suggesting that the Don River and STP are major contributors to this trend.

4.0 DERIVATION OF EFFLUENT LIMITS

In this section, several different methodologies useful for setting effluent limits are discussed. The methods discussed may be useful on their own, or in conjunction with the various toxicity tests, the details of which are presented in other component reports.

4.1 Theoretical Prediction of Dilution Due to Dispersion

McCorquodale (1983) described models for calculating the rate of effluent dilution from a diffuser outfall in the near field (initial mixing at end of pipe) and far field (dilution due to water currents and dispersion). Initial mixing at the end of pipe is dependent upon flow rate at each diffuser port (increased flow rate causes poorer dilution), water depth (improved mixing at greater depth), and relative plume buoyancy (expressed as a stability factor; more buoyant plume results in poorer dilution). Far field mixing is then treated using an unsteady state flow model involving solutions of the convective-dispersive equation for a volume source generated from the near field mixing. Further details are given by McCorquodale (1983) and references cited therein.

Pending development of MOE's mixing zone policy, the model was run for estimation of initial (near field) dilution (i.e. zero radius of mixing zone) as well as a 500 m radius of mixing zone. Dilutions were calculated for the existing outfall location (100 m diffuser discharging into a 6 m total water depth), and the proposed offshore location (1000 m diffuser discharging into a 15 m total water depth) (Gore and Storrie, 1986b). Three current speeds were used: (a) stagnation, initially considered as 0.02 m/s; (b) average conditions, 0.1 m/s; and (c) jetting, 0.2 m/s. Three Main STP discharge flow rates were also considered: (a) 11 m^3/s, which represents the summer 1987 average flow rate; (b) 15.77 m^3/s, which represents the ultimate average design flow, and (c) 35.61 m^3/s, which represents the maximum design flow for the input sewer system (Gore and Storrie, 1986b). The plume stability factor (f, McCorquodale, 1983) was taken as 0.417 (mixing in top 2.5 m of water column) with the existing outfall. This produces initial dilutions under average

conditions near to those observed (Section 3.2.2) and is in reasonable agreement with profiles taken near the end of the outfall (Section 3.2.5).

The resulting dilutions are given in Table 4.1. Dilutions were not computed for the maximum design flow (35.61 m^3/s) at the existing outfall, as this would represent an "overload" condition, which would result in partial discharge through the seawall gates. For same cases, the "stagnation" current speed of 0.02 m/s had to be increased as large flow rates into a confined space would artificially create faster currents in the near field.

The dilution factors given in Table 4.1 are expressed as a dilution ratio (X value in Section 3.2.2, where background value is assumed to be zero) and also as a percentage of source concentration. The dilution ratio can be interpreted as 1 part of effluent diluted to the stated number of parts of effluent - water mixture, i.e. 1:2.3 dilution for average currents and average STP outfall flow equals 1 part effluent plus 1.3 parts of lake water giving 2.3 parts of mixture. This dilution ratio is slightly lower (i.e. poorer dilution) than the 1987 observed results at station 1419 (Table 3.16) for conventional parameters. (Range 1:2.9 for lab ammonia to 1:7.1 for zinc). The observed results also indicate somewhat more far field dilution with distance (i.e. 3 to 15% at 500 m); however, as decay was neglected in these dilution calculations, the resulting estimates are conservative. It should be noted that parameters with significant decay factors such as fecal coliforms, total phosphorus and metals had the highest initial dilution factors in table 3.16; those with less decay generally had initial dilutions below 1:4. Nevertheless, it was felt that these should represent a realistic range of expected dilutions should the new outfall be built.

A selected subset of these dilutions are being used in conjunction with laboratory and field toxicity tests, to estimate acceptable effluent strengths based on the precept of no rapid lethality in the mixing zone and no chronic effects beyond the edge of the mixing zone (Policy 5, MOE, 1984).

TABLE 4.1: RESULTS OF DILUTION MODEL RUNS FOR CURRENT AND PROPOSED MAIN STP OUTFALLS

Main STP Flow (m^3/s)	Current Speed m/s	Mixing Depth From Surface m	Initial Dilution (no m.z.)	Dilution at 250 m	Dilution at 500 m
(a) Existing Outfall (100 m diffuser length in 6 m total water depth)					
11	0.05	2.5	1.1 (88%)	2.1 (47%)	3.0 (33%)
	0.1	2.5	2.3 (44%)	3.2 (32%)	4.3 (24%)
	0.2	2.5	4.5 (22%)	5.6 (18%)	6.2 (16%)
15.77	0.06	3.	1.1 (88%)	1.3 (76%)	1.7 (58%)
	0.1	3.	1.9 (53%)	2.4 (42%)	3.1 (32%)
	0.2	3.	3.8 (26%)	4.3 (23%)	4.6 (21%)
(b) Proposed Outfall (1000 m diffuser length in 15 m total water depth)					
11	0.02	3.	5.5 (18.3%)	15.7 (6.4%)	24.7 (4.1%)
	0.1	3.	27.3 (3.7%)	33.8 (3.0%)	42.9 (2.3%)
	0.2	3.	54.5 (1.8%)	61.7 (1.6%)	66.4 (1.5%)
15.77	0.02	3.	3.8 (26.3%)	10.9 (9.1%)	17.2 (5.8%)
	0.1	3.	19.0 (5.3%)	23.5 (4.3%)	29.9 (3.4%)
	0.2	3.	38.0 (2.6%)	42.9 (2.3%)	46.3 (2.2%)
35.6	0.03	3.	2.5 (40%)	5.0 (20%)	7.0 (14.3%)
	0.1	3.	8.4 (11.9%)	10.4 (9.6%)	13.2 (7.5%)
	0.2	3.	16.8 (5.9%)	19.0 (5.3%)	20.5 (4.9%)

Note: Current speeds of 0.02-0.06 m/s represent "stagnation" speeds of 0.1 m/s, "average", and 0.2 m/s, "jetting".

4.2 Use of Theoretical Dilution Model to Derive Effluent Limits Based Upon Water Quality Results

The theoretical dilution factors given above may be used to estimate the extent of loading reduction required based upon the water quality results in the effluent (section 3.1) and Lake Ontario in the vicinity of the Main STP outfall.

Derivation of water-quality based effluent limits is based upon the premise of achieving PWQO at the edge of a defined mixing zone, e.g. zero, 250 or 500 m radius from the outfall diffuser. For this purpose, parameters which are most frequently in exceedence are discussed. Table 3.17 shows that residual chlorine, ammonia and total phosphorus are almost always in exceedence at station 1419 near the end of pipe; of the heavy metals surveyed, iron, copper and cadmium are frequently in exceedence. Of the organic parameters sampled, lindane (Table 3.18) is frequently in exceedence. In addition, across the Toronto Waterfront, PCBs frequently exceed the PWQO of 1 ng/L as determined by APLE sampling (section 3.3.2). Within several kilometres of the Main STP (stations 1536, 2886, 2892 and 2029), the average concentration of total PCBs was found to be 0.3, 0.5 and 1.0 ng/L during the three 1987 surveys (Halfon, 1990). These figures are lower than the values given in Table 3.21 because the latter include results for several points impacted by other sources. The average of the above values (0.6 ng/L) has been used as a "background" value in this chapter; however, considering the range of values observed, "background" could be 1.0 ng/L or higher, in which case required effluent reductions would be 100% for all scenarios. This fact should be kept in mind in evaluating the proposed effluent reductions for PCBs. However, it can be anticipated that abatement measures taken to reduce the loadings of other substances of concern should also reduce PCB loadings and have a beneficial effect on concentrations in various components of the ecosystem.

The Toronto MISA team has recommended that water quality based effluent limits be derived on the basis of 95% compliance with objectives or guidelines. For this basis, the probability distributions of loadings for parameters of concern (section 3.1.2) are used. For

substances such as total phosphorus in which the observed background concentration (cluster 4; section 3.3.1) is a significant fraction of the objective or guideline, the allowable increase in concentration near the outfall is used. In addition, as the dilution characteristics of the proposed outfall location are much better than the present location (Table 4.1), effluent limits are derived separately for each location. These will be discussed in turn.

4.2.1 Present Outfall Location

Calculations have been performed for mixing zones of zero, 250 and 500 m, assuming average currents (0.1 m/s) and average Main STP flow (960 x 10^3 m^3/d = 11 m^3/s) (dilution factors of 2.3, 3.2 and 4.3, Table 4.1). As we are interested in the maximum allowable increase over background, the allowable effluent concentration (c) calculated as follows (500 m):

$$c = (4.3 \times (PWQO - BGD)) + BGD$$

The allowable concentration is then multiplied by the corresponding flow to obtain the allowable loadings, which is compared with observed 1987 95 percentile loadings (Figures 3.10 - 3.15) to derive the required loading reductions. The results are given in Table 4.2. Similar calculations were done for the ultimate average design flow (15.77 m^3/s); as these give similar loading reductions, they are not reproduced here.

Adjacent to the outfall (zero mixing radius), severe reductions in effluent levels are predicted, ranging from 68% for lindane to 98% for total phosphorus and 99.7% for chlorine residual. If a mixing zone of 500 m radius is permitted, the required reductions range from 42% for iron and lindane, to 96% for total phosphorus and 99.4% for chlorine residual. Intermediate results are obtained for a 250 m radius mixing zone.

The model was also used to estimate the mixing zone length required for dilution of the total phosphorus concentration to the 20 ug/L guideline for the prevention of nuisance

algae growth, assuming effluent concentrations of 0.5 and 1.0 mg/L and a background concentration of 10 μg/L. (i.e. 1:49 and 1:99 total dilutions, respectively). The results, for average currents and average Main STP flow, were 17 and 35 km, respectively. At these high distances, the model predictions may only be considered as crude approximations, as the model neglects small-scale variability in currents and dispersion, which strongly affect the dilutions.

4.2.2 Proposed Outfall Location

Effluent requirements for the proposed location are also given in Table 4.2. Due to the much greater extent of dilution predicted as a combined result of increased water depth and diffuser length, the present loadings are predicted to satisfy requirements for all parameters but total phosphorus, chlorine residual and PCBs at all distances, and ammonia at zero mixing radius only. Required reductions for chlorine residual range from 94 to 97%, and for total phosphorus, 65 to 80%, and for PCBs, 58 to 75%, dependent on mixing zone radius.

As with the present outfall above, the model was used to estimate the mixing zone length required for dilution of total phosphorus to the PWQG of 20 μg/L from effluent concentrations of 0.5 and 1.0 mg/L, assuming a background concentration of 10 μg/L. The result indicates that distances of 0.7 and 3.6 km are required for dilution to 20 μg/L under these conditions, respectively.

4.3. Dilution Envelope Modelling

Drogue-tracking involves the tracking of multiple water-sail drogues (current tracers) released simultaneously at a point source. The positions of the drogues then give a measure of the direction and the spread of a plume as a function of the time. Current direction information from the 1986 drogue cluster tracking study was used in determining down-current dilution envelopes (pages 4.8 - 4.9); however, these data were insufficient to develop statistical dilution-time relationships due to the frequent presence of non-steady

Table 4.2: **Effluent requirements based on McCorquodale dilution model**

Parameter	Background µg/L unless stated (BGD)	PWQO -BGD	Observed 1987 95%ile Load (Kg/d)	Mixing zone 0m			Mixing zone 250m			Mixing zone 500m		
				Outfall concn µg/L	Allowable Load Kg/d	% reduction required	Outfall concn µg/L	Allowable Load Kg/d	% reduction required	Outfall concn µg/L	Allowable Load Kg/d	% reduction required
(a) Existing Outfall Location												
NH-3 - N(mg/L)	0.02	1.0*	3.2×10^4	2.3 mg/L	2200	93	3.2 mg/L	3100	90	4.3 mg/L	4100	87
Total P**	10	10	1200	24	23	98	33	32	97	53	51	96
Fe	20	280	2000	660	630	69	920	880	56	1220	1160	42
Cu	1	4	40	10	10	75	13	12	70	18	17	58
Cd	~0	0.2	3.3***	0.46	0.44	87	0.64	0.61	62	0.86	0.83	75
Lindane (ng/L)	1	9	65 g/d	22 ng/L	21 g/d	86	29 ng/L	28 g/d	57	40 ng/L	38 g/d	42
Chlorine residual	~0	2	1400	4.6	4.4	99.7	6.4	6.1	99.6	8.6	8.3	99.4
PCB (ng/L)	0.6	0.4	40 g/d	1.5 ng/L	1.4 g/d	97	1.9 ng/L	1.8 g/d	96	2.3 ng/L	2.2 g/d	95
(b) Proposed Outfall Location												
NH-3 - N(mg/L)	0.02	1.0*	3.2×10^4	23.5 mg/L	2.3×10^4	28	33.8 mg/L	3.2×10^4	0	42.9 mg/L	4.1×10^4	0
Total P**	10	10	1200	245	235	80	348	334	72	439	421	65
Fe	20	280	2000	6600	6300	0	9600	9200	0	12000	11500	0
Cu	1	4	40	95	91	0	136	131	0	172	165	0
Cd	~0	0.2	3.3***	4.7	4.5	0	6.8	6.5	0	8.6	8.3	0
Lindane (ng/L)	1	9	65 g/d	210 ng/L	200 g/d	0	300 ng/L	290 g/d	0	390	370	0
Chlorine residual	~0	2	1400	47	45	97	88	85	95	86	83	94
PCB (ng/L)	0.6	0.4	40 g/d	10 ng/L	10 g/d	75	14 ng/L	13 g/d	68	18 ng/L	17 g/d	58

Results are based upon average current velocities of 0.1 m/s and an initial dilution of 1:2.3 (existing outfall) and 1:27.3 (proposed outfall)

Note:

* *Assuming pH = 7.6, T = 23.5 C, approximate "worst case" conditions near the present Main STP outfall*

** *Guideline (0.02 mg/L) for prevention of nuisance algal growth*

*** *1986 value*

state and eddy conditions. Consequently, information from other STP studies was also used to develop these relationships.

Between 1984 and 1986, a statistical dilution and time relationship for steady, conservative sources, was developed for nearshore surface waters (Figure 4.1; Palmer, 1988):

$$\frac{C}{C_o} = 15.55\ t^{-.97} \tag{4.2.1}$$

Since the conductivity of the water is related to the amount of solids dissolved in the water, it is possible to develop dilution envelopes from Equation 4.2.1, based upon the known conductivity:

$$\frac{C}{C_o} = \frac{K - K_{bac}}{K_o - K_{bac}} \tag{4.2.2}$$

where: K_o is the value of the surface conductivity at the STP outfall, and

K_{bac} is the background conductivity.

Using the conductivity data collected in 1987, we can estimate the dilution using Equation 4.2.2 and obtain the value of the time from Equation 4.2.1. Knowing the distance to a particular station then defines the velocity. The average velocity was estimated for stations 1419 to 2891, which lie in a southerly direction from the outfall, and stations 1419 to 2209, which lie in an easterly direction from the outfall, and dilution envelopes were developed (see Figure 4.2). From the statistical dilution/time relationship of Figure 4.1, we can estimate the error involved since, for a particular value of the dilution, the predicted time t_o ranges between t_{min} and t_{max}. The error calculated is shown in Figure 4.2 for a 10% dilution.

FIGURE 4.1
Dimensionless Dilution versus Time Relationship

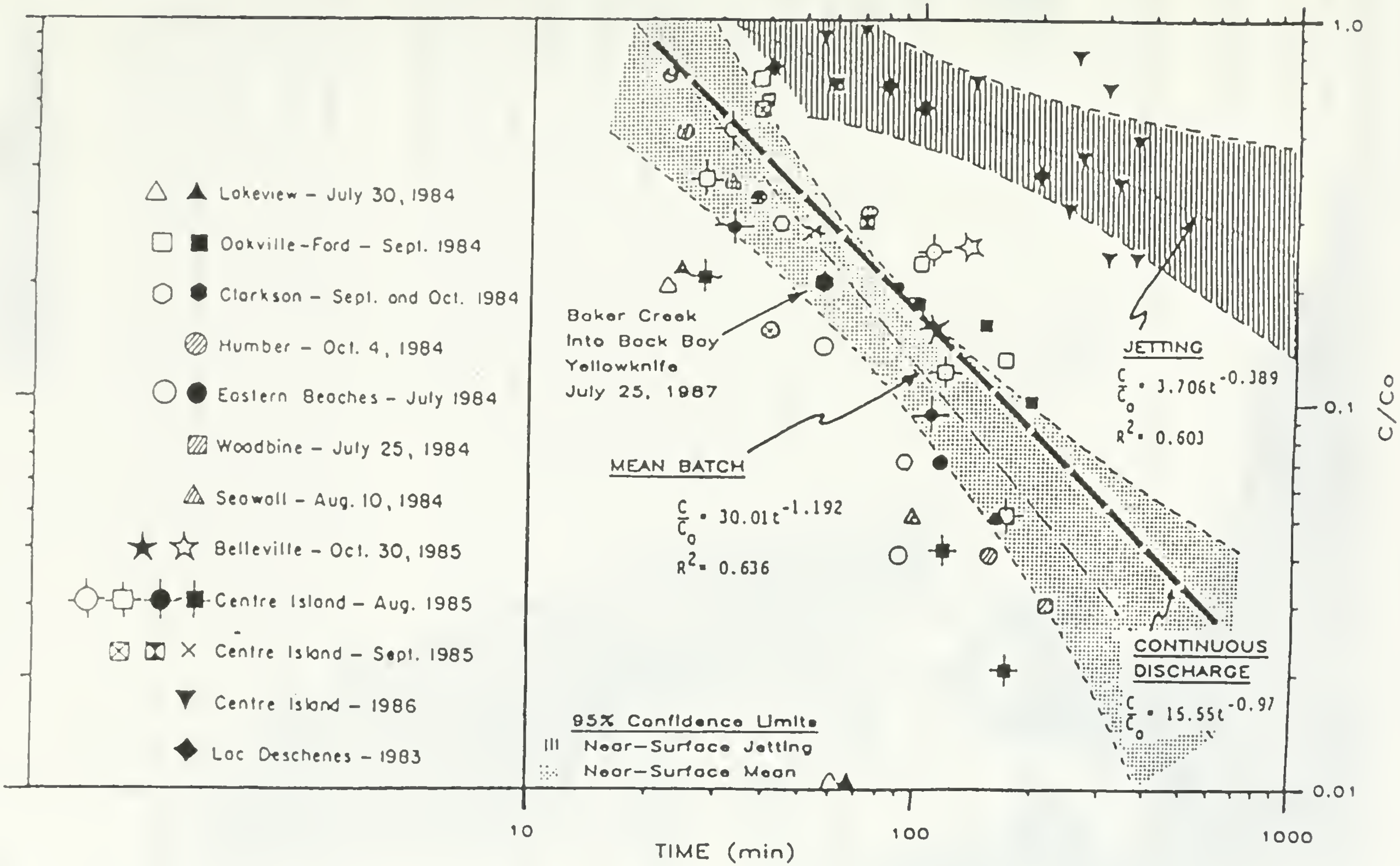
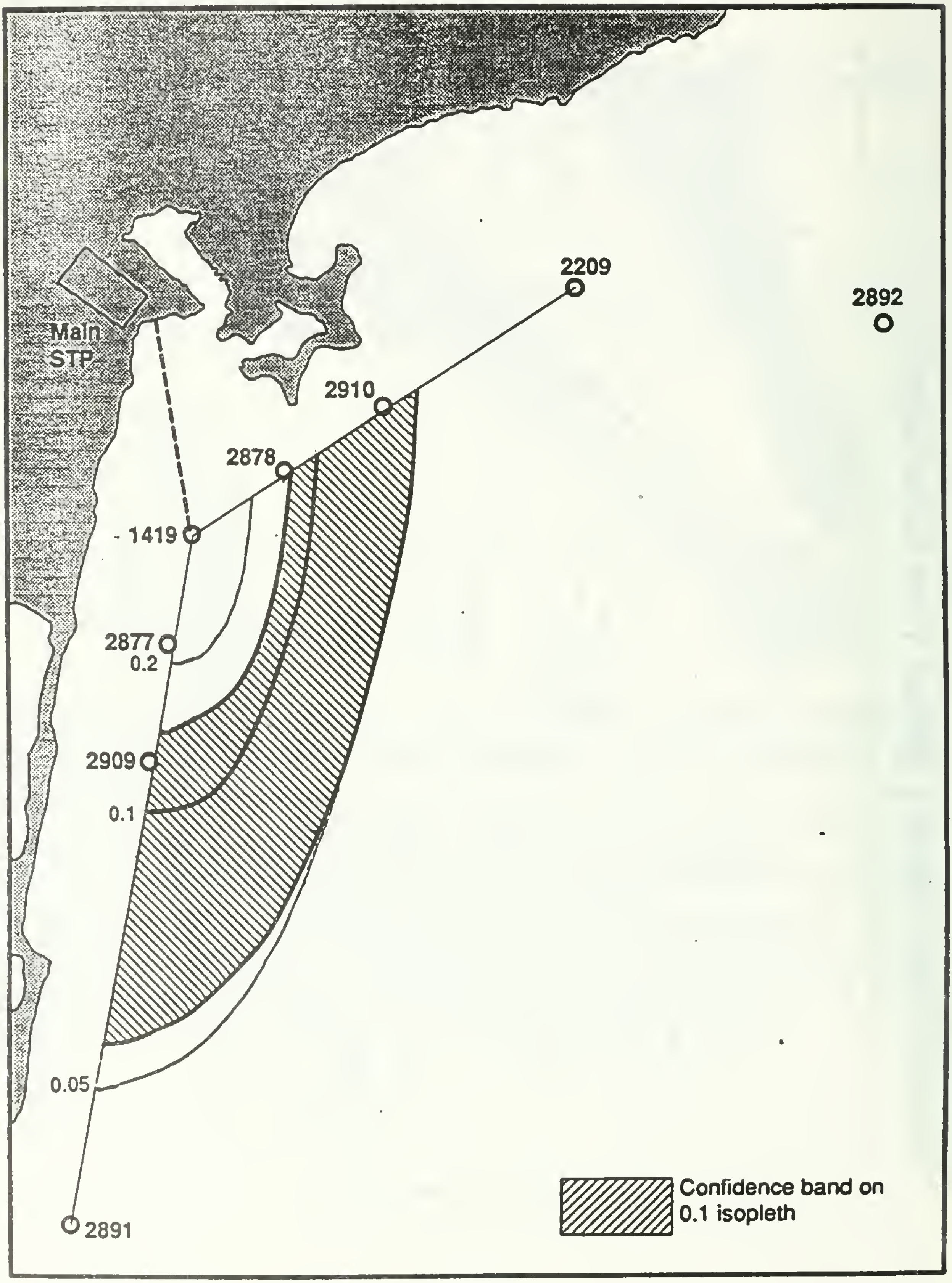


FIGURE 4.2
Conductivity Dilution Isopleths at 0.5 m in 1987



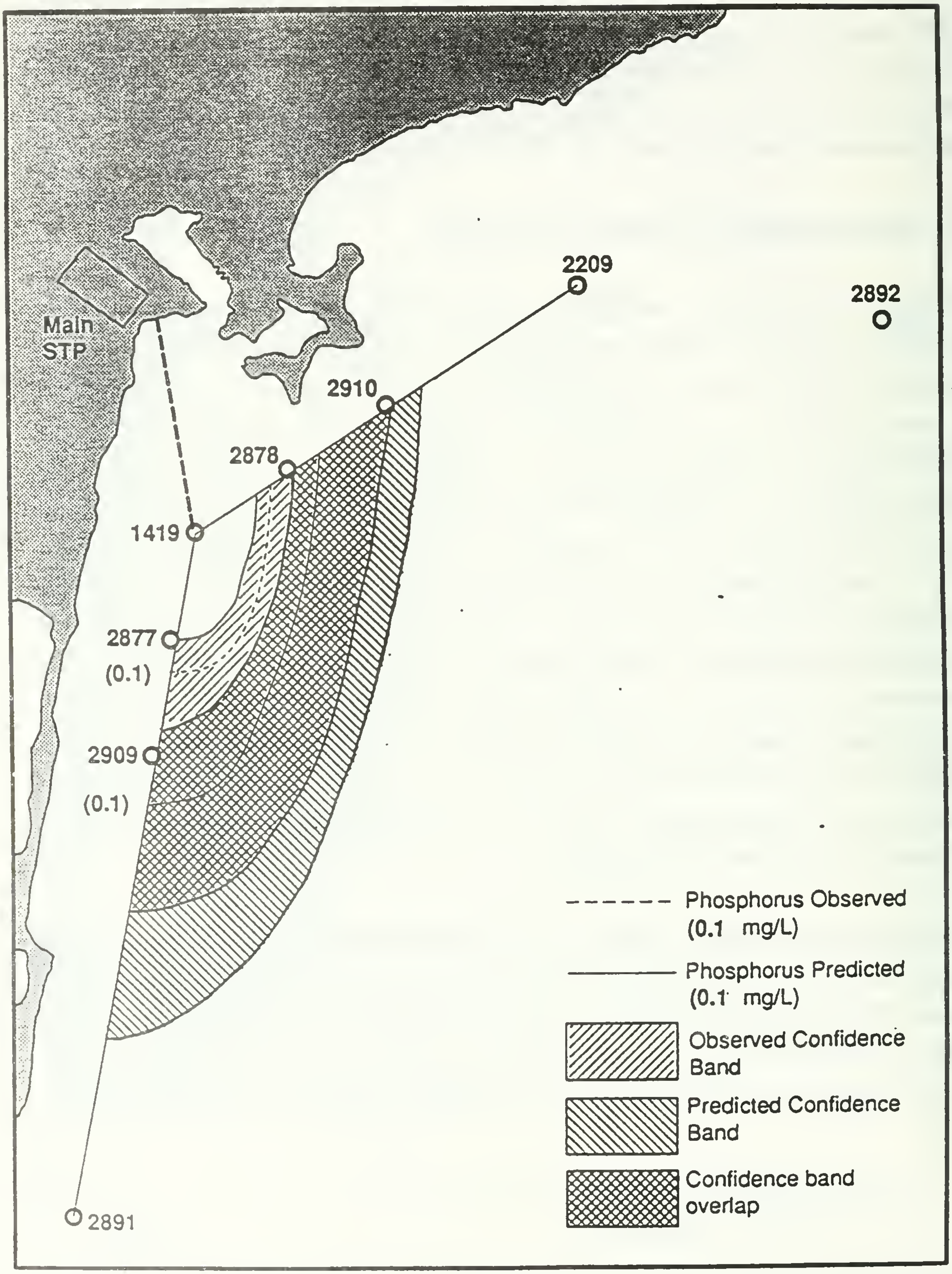
An observed concentration isopleth for phosphorus calculated directly from the Main STP study data (see Section 3.2.2) and the predicted concentration isopleth for a strictly conservative source, are compared in Figure 4.3 for a 0.05 mg/L concentration, along with the error for each isopleth. The more rapid observed dilution in Figure 4.3 represents the non-conservative nature of phosphorus due to bio-uptake, sedimentation, etc.

4.4 Effluent Dilution from Plume Tracking Results

Derivation of water quality based effluent limits is based upon the premise of achieving PWQO at the edge of a defined mixing zone, e.g. 500 m radius from the outfall diffuser. Tables 3.17 and 3.18 show which PWQOs are exceeded at the outfall (Station 1419). At a water depth of 0.5 m, the PWQOs are exceeded for free chlorine, ammonia and phosphorus on all sampling days, and for iron, copper and cadmium 40%, 30% and 20% of the sampling days. The initial dilution from jetting from the outfall for residual chlorine was 1:3.0, for ammonia 1:3.1, for phosphorus 1:5.0, for iron 1:4.1 and copper 1:5.4 (Table 3.16). The initial dilutions for the outfall diffuser should be the same for all water quality parameters. The variations determined for the different parameters are a consequence of the different sampling times for the effluent, receiving water and estimating the background concentrations in the lake. If the dilutions for the preceding parameters are averaged, the mean dilution achieved by the diffuser outfall is 1:4.1. This is somewhat higher than the value of 2.3 predicted for average currents (0.1 m/s) and average effluent flow from the dilution model discussed above (Table 4.1); it is approximately equal to the predicted dilution at 500 m under these conditions.

Averaged dilution envelopes (Figures 4.1 to 4.3) were calculated from 1987 concentration data at stations close to the outfall. The mean velocity in the southerly direction was found to be 0.12 m/s (S.D. = 0.05 m/s) and in an easterly direction 0.06 m/s (S.D. = 0.03 m/s). The size of these dilution envelopes is directly proportional to the receiving water velocity - i.e. doubling the velocity would result in a doubling of the size of the non-compliance

FIGURE 4.3
Predicted versus Observed Phosphorus Concentration Isopleth at 0.5 m in 1987



zone. This fact is also illustrated in the size of non-compliance zones obtained from one-day plume tracking experiments in June 1987 (section 3.2.3; Figures 3.36 - 3.38 and Appendix 5).

The rate of far-field dilution for conductivity, ammonia and chlorine residual may be estimated by plotting the dilution factors (X or 1/X) against distance from the outfall on a semilogarithmic scale, assuming first order decay with distance. Under this assumption, the rate constant of decay K (base 10) is simply the negative of the slope of the decay curve. The dilution rate, to 100 m (z) may then be expressed as:

$$\int_{1.0-z}^{1.0} \frac{dc}{c} = \int_{0}^{100} (-k\ dx) \tag{4.3.1}$$

where c = concentration
x = distance from outfall.

Assuming base 10, equation 4.3.1 is simplified to

$$\log 1.0 - \log (1.0 - z) = -100\ k$$

$$\text{and} \qquad z = 1 - 10^{100k} \tag{4.3.2}$$

The percent dilution is then simply 100z%.

The Y-intercept of the same plot represents an estimate of initial dilution, as it is the value of the dilution factor at zero distance.

Using this methodology, dilution rates have been calculated for the plume tracking surveys undertaken in June 1987 (Figures 3.13-3.15 and Appendix 5). Only down-current information in the direction of maximum concentration was used; in addition, information obtained at distances at which the effects of eddies and non-steady state conditions occurred

was neglected. Dilution curves for conductivity, ammonia and chlorine residual obtained using these assumptions are given in Figures 4.4 - 4.6. These curves emphasize information obtained within about 2 km of the outfall, as it is within this zone that we are most interested in dilution calculations; furthermore, data collected at greater distances are more subject to the effects of eddies and non-steady state conditions.

Dilution rates and initial dilutions as calculated above are given in Table 4.3 for June 1987 plume tracking data. Decay rates were not calculated for June 18 (stagnation) due to lack of ammonia and chlorine residual data at intermediate points in the current direction. Under jetting conditions (June 17 and 19), non-linear decay tended to be present; the decay rates calculated above represent the average decay at distances between 0.5 and 2.5 km from the outfall, and neglect "pockets" of higher concentration sometimes seen at greater distances (Figures 3.14b, 3.15b).

Within the distances considered above, physical transport appears to be the major determinant of the dilution rate, with the highest dilutions being found under stagnation (June 18) and the lowest under jetting (June 17, 19). Within this distance and neglecting June 18, the dilution rates and initial dilutions for conductivity and ammonia were similar. This suggests that processes such as nitrification, bio-uptake and volatilization play only a minor role in ammonia decay over this time period. Furthermore, initial dilutions (1:2.9 to 1:4.8) are similar to or slightly less than the average (1:4.1) predicted from water chemistry data. By contrast, chlorine residual has a lower initial dilution but a higher dilution rate. While decay is responsible for the higher dilution rate, the reason for the lower initial mixing is unknown.

TABLE 4.3: DILUTION RATES AND INITIAL DILUTIONS JUNE 1987 PLUME TRACKING RUNS

		Decay constant $k(m^{-1})$			Dilution Rate Percent/100 m			Initial Dilution		
Date	Current Direction	Conductivity	Field Ammonia	Chlorine Residual	Conductivity	Field Ammonia	Chlorine Residual	Conductivity	Field Ammonia	Chlorine Residual
June 16	East	.00080	.00092	.00125	17	19	25	3.8 (26%)	3.4 (29%)	2.1 (48%)
June 17	South	.00023	.00022	.00098	5	5	20	4.1 (24%)	4.8 (21%)	1.5 (68%)
June 18	North	.00093	-	-	19	-	-	3.0 (33%)	-	-
June 19	East	.00024	.00015	.00052	5	3	11	2.9 (35%)	4.6 (22%)	4.7 (21%)
	Mean				12 (9)*	9	19	3.5 (29%)	4.3 (24%)	2.8 (46%)
	S.D.				8 (7)*	7	7	0.6 (5%)	0.8 (4%)	1.7 (24%)
								*3.6 (28%)		
								*0.6 (6%)		

Note * Excluding June 18

Figure 4.4

Plot of dilution vs. distance from Main STP outfall Conductivity, June 1987

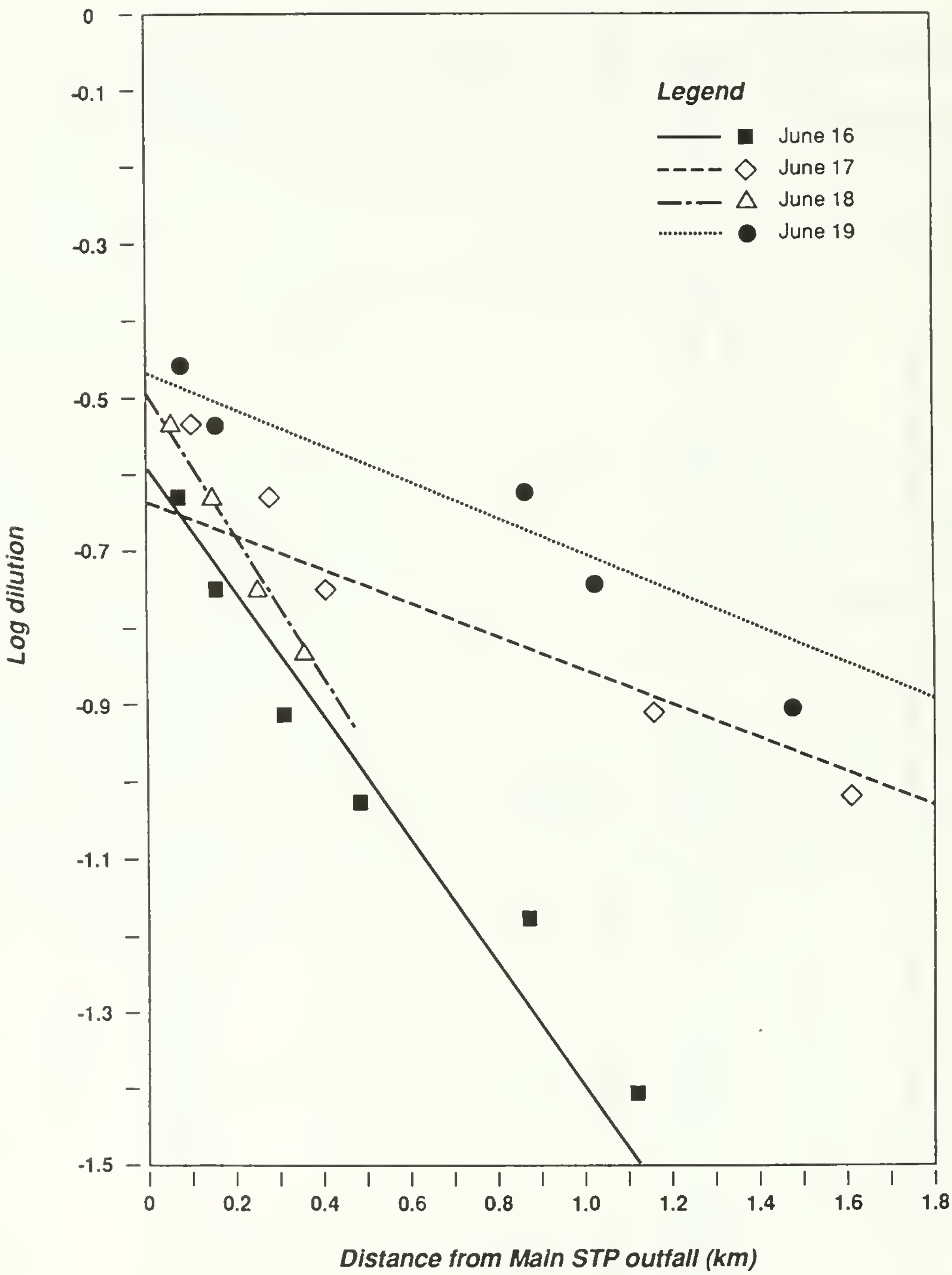


Figure 4.5

Plot of dilution vs. distance from Main STP outfall Ammonia, June 1987

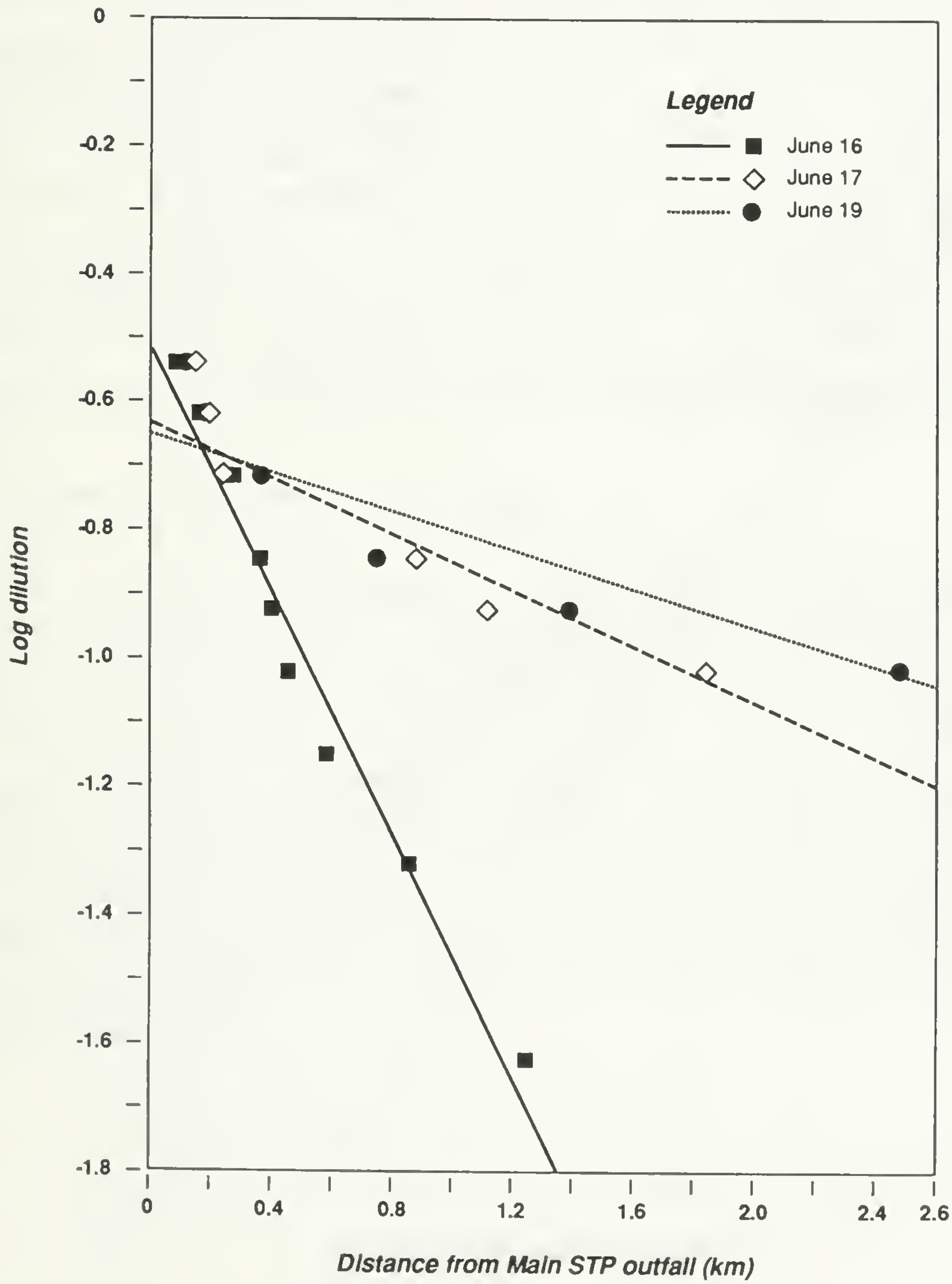
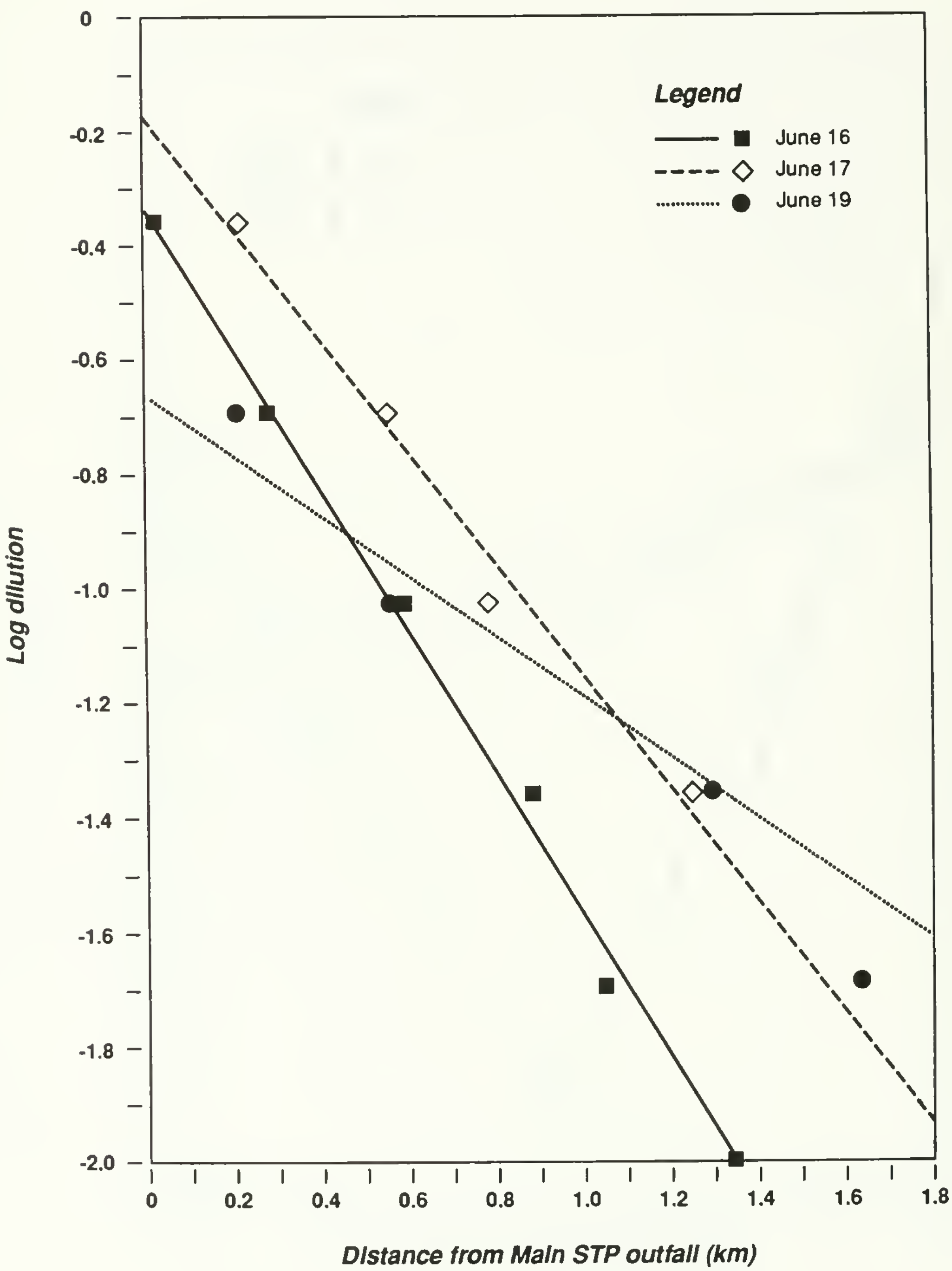


Figure 4.6

Plot of dilution vs. distance from Main STP outfall Chlorine residual, June 1987



A limited amount of additional data are available for 1986. Receiving water data are available at station 1419 near the outfall, plus stations 1431 to 1434. Drogue data are also available to define the downstream direction for dilution calculation; it was found that the conductivity at discrete points rather than concentration contours were used in the regressions. Station 1419 was also used due to the small number of data points available, despite the fact that concentrations at this station are affected by turbulent near-field effects. Using only down-current data, the percentage dilution rates per 100 m are given in Table 4.4. It can be seen that for ammonia and chlorine residual, the ranges and average values of both initial and far-field dilution are similar in both survey years. Data for fecal coliforms are also included. The high but variable initial dilutions in August and September reflect the effect of chlorination; when this is absent in November, very low initial dilutions but somewhat greater far-field dilutions were found for this parameter.

4.5 Effluent Limits Based on Plume Tracking

The plume tracking results presented above may be used in conjunction with the 1987 effluent data (section 3.1) to derive another estimate for effluent limits. Background data are also used in a manner identical to that described in section 4.2. As these calculations are based on observed data for the existing outfall, it is not possible to estimate effluent limits for the proposed outfall using this method. As it is desirable to deal with average to worst case conditions, the "stagnation" results of June 18 are neglected and the following calculations are based upon the average of the other three survey days (average to jetting current conditions). Conductivity is used as a surrogate for parameters not measured in the plume, as it shows significant correlation between the Main STP and area water quality stations (Table 3.19).

TABLE 4.4: DILUTION RATES AND INITIAL DILUTIONS
1986 DROGUE TRACK SURVEY DATA

Date (1986)	Drogue Direction	Decay constant $k(m^{-1})$ Field Ammonia	Decay constant $k(m^{-1})$ Chlorine Residual	Decay constant $k(m^{-1})$ Fecal Coliforms	Dilution Rate Percent/100 m Field Ammonia	Dilution Rate Percent/100 m Chlorine Residual	Dilution Rate Percent/100 m Fecal Coliforms	Initial Dilution Field Ammonia	Initial Dilution Chlorine Residual	Initial Dilution Fecal Coliforms
Aug. 12	East	.00037	.00051	.00059	8	11	13	3.0 (33%)	1.9 (52%)	33.1 (3%)
Aug. 13	East	.00074	.00157	.00232	16	30	41	2.5 (40%)	1.1 (95%)	8.3 (12%)
Aug. 14	West	.00082	.00143	-	17	28	-	3.2 (31%)	4.3 (23%)	-
Sep. 8	East	.00048	.00052	-	10	11	-	3.4 (29%)	4.3 (23%)	-
Sep. 9	North	.00036	.00056	.00052	8	12	11	4.7 (21%)	3.4 (29%)	158. (0.6%)
Sep. 10	East	.00039	.00054	.00091	8	12	19	3.0 (33%)	1.7 (58%)	26.4 (4%)
Nov. 4	East	.00059	-	.00458	13	-	65	13.2 (7.6%)	-	1.4 (69%)
Nov. 6	East	.00093	-	.00156	13	-	30	3.4 (29%)	-	1.9 (53%)
Mean					11	17	21*	4.5 (28%)	2.8 (47%)	56. (5%)*
S.D.					4	9	14*	3.6 (10%)	1.4 (28%)	69. (5%)*
							48**			1.7 (61%)**
							24**			0.4 (11%)**

Note * August-September data only
** November mean and standard deviation

Given the average dilution rates (z) per 100 m for 1987 and average initial dilution at the outfall (ID), the average allowable effluent concentration to achieve compliance within a specific radius of the outfall may be calculated as follows:

(a) Concentration at zero radius:

$$c_0 = (PWQO - BGD) * ID \qquad 4.3.3$$

(b) Concentration at radius x in units of 100 m

$$c_0 = c_x (1 - Z)^{-x} \qquad 4.3.4$$

i.e. at 500 m for a dilution of 9%/100 m, and allowable concentration is 1.60 C_o = 5.8 (PWQO-BGD), assuming an average initial dilution of 1:3.6. It should be noted that this allowable concentration is the excess over background, therefore the background value is added to the above concentration to give the allowable value, i.e. 6.6 (PWQO-BGD) + BGD.

If the goal is that of achieving compliance 95% of the time, then the loading calculated from the above concentration should be compared with the 95th percentile of the observed loading in order to estimate the required loading reductions. The results are given in Table 4.5.

Calculated loading reductions at 500 m range from 22% for iron and lindane, to 98.9% for chlorine residual. The stringent loading reductions required reflect the limited amount of mixing at the present outfall site, and would be only slightly less if a larger mixing zone (e.g. 1000 m) were allowed.

4.6 Fate and Transport Modelling

A simulation study of the fate and transport of toxic organic contaminants in the Toronto Waterfront was conducted by Halfon (1990) using ultra-trace organic contaminant data collected in 1987 as part of this study (sections 3.1.1, 3.3.2, 3.3.3) along with external

TABLE 4.5: LOADING REDUCTIONS BASED ON PLUME TRACKING RESULTS

			Adjacent to outfall (0m)			500 m from outfall		
PARAMETER	PWQO -BGD µg/L	1987 95 Percentile Loading kg/d	Allowable Effluent Concen. µg/L	Allowable Loading kg/day	% Reduction Required	Allowable Effluent Concen. µg/L	Allowable Loading kg/day	% Reduction Required
NH_3*	1000.	3.2×10^4	4300.	4.1×10^3	88	6900.	6.6×10^3	79
Cl_2 residual	2.	1400.	5.6	5.4	99.6	16.	15.	98.9
Total P**	10.	1200.	46.	44.	96.	68.	65.	95.
Fe	280.	2000.	1030.	990.	51.	1630.	1560.	22.
Cu	4.	40.	15.	14.	65.	24.	23.	43.
Cd	0.2	3.3 (1986)	0.7	0.7	79.	1.2	1.1	67.
Hg	0.2	0.081	0.7	0.7	0.	1.2	1.1	0.
Lindane***	9.	65.	33.	32.	51.	53.	51.	22.
PCBs***	0.4	40.	2.0	1.9	95.	2.9	2.8	93.

Note: * Based upon pH = 7.6 and temperature = 23.5°C
** Guideline of 20 µg/L for prevention of nuisance algal growth (background assumed to be 10 µg/L)
*** Concentration in ng/L; loading in g/d.

Parameters other than NH_3 and Cl_2 residual were calculated using ID = 1:3.6 and far-field dilution of 9%/100 m, as estimated for conductivity on June 16, 17 and 19, 1987. Loadings were calculated using an average flow of 960×10^3 m^3/d.

loadings (Niagara River, atmospheric) and currents as simulated by the Rand model (Gore and Storrie, 1989).

The TOXFATE model used in this study simulates the concentrations of organic contaminants in water, sediments and several levels of biota. It accounts for processes such as volatilization, sorption, bio-uptake and sedimentation, as well as the hydrodynamic transport of contaminants input to the lake from Toronto-area sources (STPs and tributaries) and distant sources (Niagara River and the atmosphere).

The objectives of this study included prediction of contaminant concentrations in the area surrounding the Toronto Main STP as well as the entire waterfront, estimation of the relative contribution of various sources to contaminant concentration, and estimation of the extent of loading reductions required to limit the zone of non-compliance with PWQO to within 500 m of the outfall. The model scenario that considered the zone near the Main STP outfall was used to compare with the estimates of required loading reductions from above.

<u>Near-Outfall Scenario:</u>

A load of 100 g/day of a hypothetical contaminant was discharged into the lake at the Main STP outfall, and its concentration in the grid square immediately adjacent to the outfall, plus those in the next nearest grid squares (i.e. 500 m from the outfall) were followed for a 12-day modelling period. As the residence time of a contaminant in such a small zone is very small, biochemical decay was neglected and physical transport (advection and dispersion) was the only dilution mechanism. Every five minutes, the concentration at the outfall grid square and the maximum concentration at the adjacent grid squares (i.e. worst case) were saved as two separate time series. These were analyzed by frequency and probability methods. A similar run was done for each of the three 1987 modelling periods,

both for the present outfall and for the proposed offshore outfall location (Gore and Storrie, 1986b).

Figure 4.7 shows the frequency distribution of concentrations at the present location when all thee modelling periods are combined, and Figure 4.8 shows similar information for the proposed outfall. It is observed that with a loading of 100 g/day, the most likely concentrations at the present outfall are between 1 and 2 ng/L; very little additional dilution is observed at 500 m. With the proposed location, however, Figure 4.8 shows most likely concentrations of 0.1 to 0.2 ng/L at both distances - i.e. an improvement by a factor of 10. Some shifts in maximum concentration and shape of the distribution occur when data from individual months are examined; the reader is referred to Halfon (1990) for details.

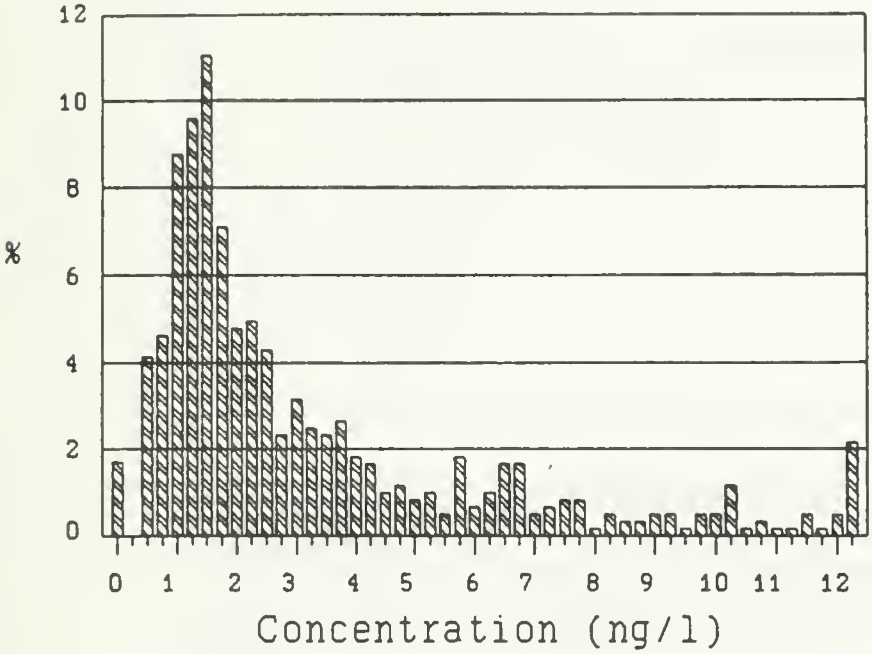
These results may also be plotted as cumulative frequency distributions - i.e. the probability of observing concentration below any value vs. that concentration value (Figure 4.9). With a loading of 100 g/day at the present outfall, there is a 95% probability that the concentration will be less than 11.5 ng/L at 0 m, and 8 ng/L at 500 m. With the proposed outfall, the 95% probability values drop to 3.3 ng/L at 0 m and 1 ng/L at 500 m.

Both sets of results may be placed in the perspective of an actual contaminant simply by multiplying by the relative load, since only physical dilution and no background contamination are assumed. For example, the observed 1987 PCB loading from the Main STP is 16.8 g/day (Table 3.2 (d)). The 95% probability concentrations for the various cases are found by multiplying the values above by (16.8/100), i.e. for the present outfall they are 1.9 and 1.3 ng/L at 0 and 500 m, and for the proposed outfall they are 0.55 and 0.17 ng/L. This suggests a further loading reduction by a factor of 1.9 is required to meet PWQO (1 ng/L) at the outfall in the present case; no loading reduction is required in the proposed case. However, it must be remembered that this is assuming no background concentration, an assumption which is not accurate for PCBs (see Halfon 1990). While reduction of loadings from the Main STP will be most beneficial for some compounds like chloroben-

FIGURE 4.7 :

Present STP - All Periods

Frequency of Concentrations at 0 m



Present STP - All Periods

Frequency of Concentrations at 500 m

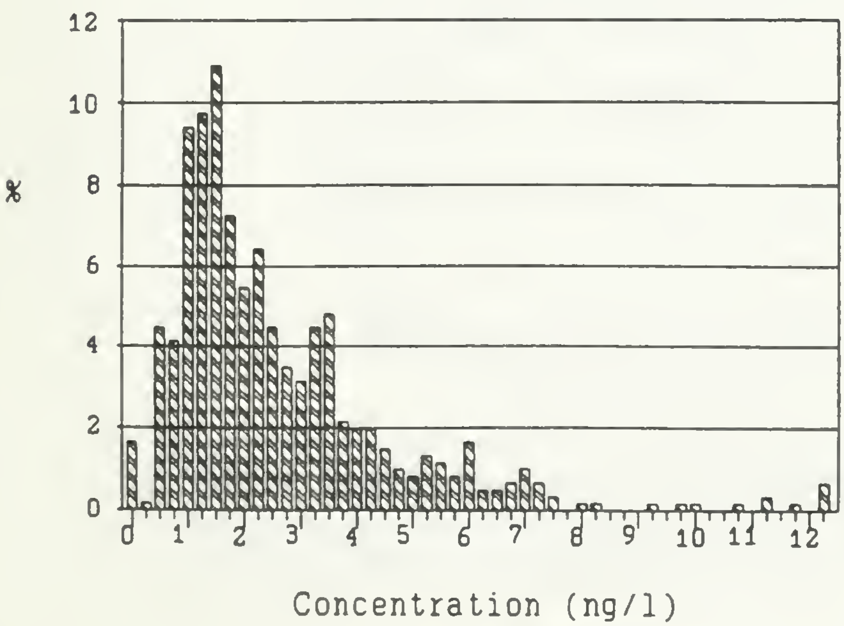
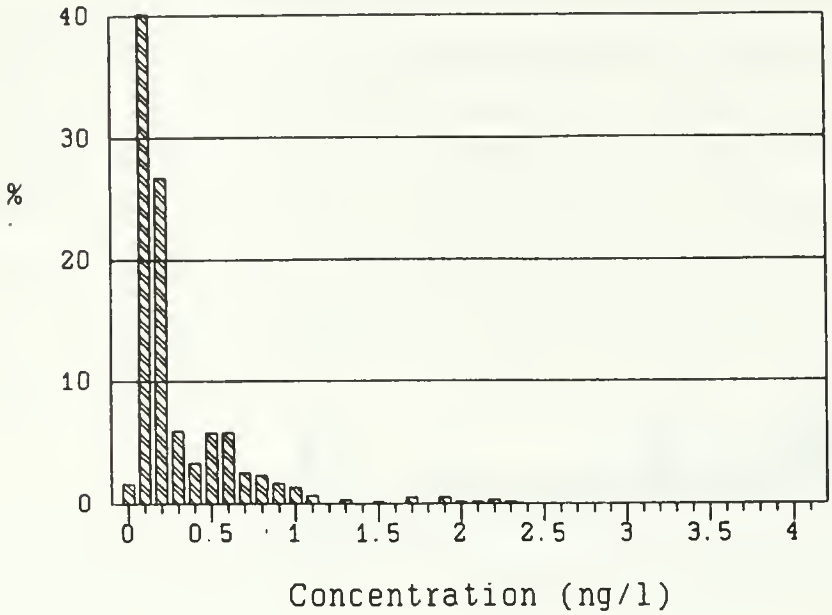


FIGURE 4.8:

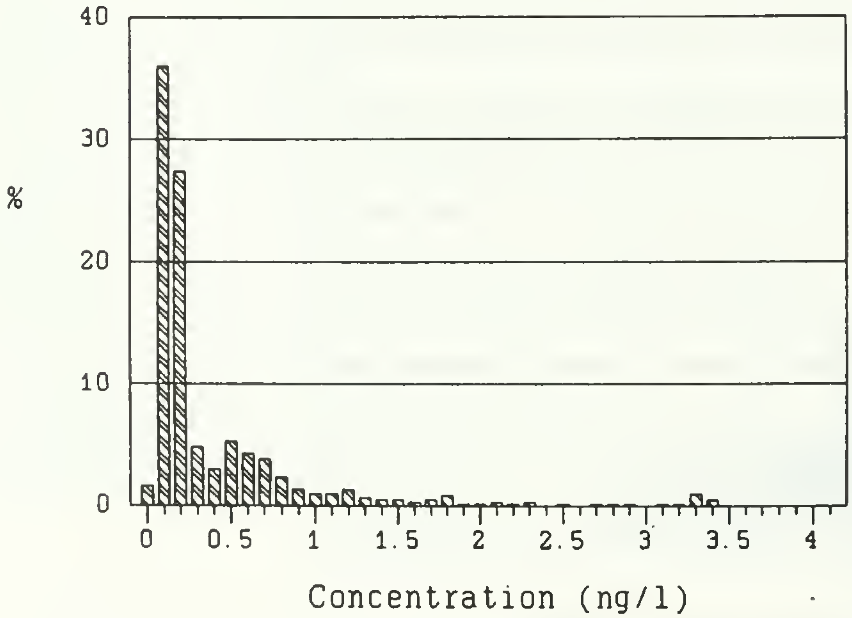
Proposed STP - All Periods

Frequency of Concentrations at



Proposed STP - All Periods

Frequency of Concentrations at



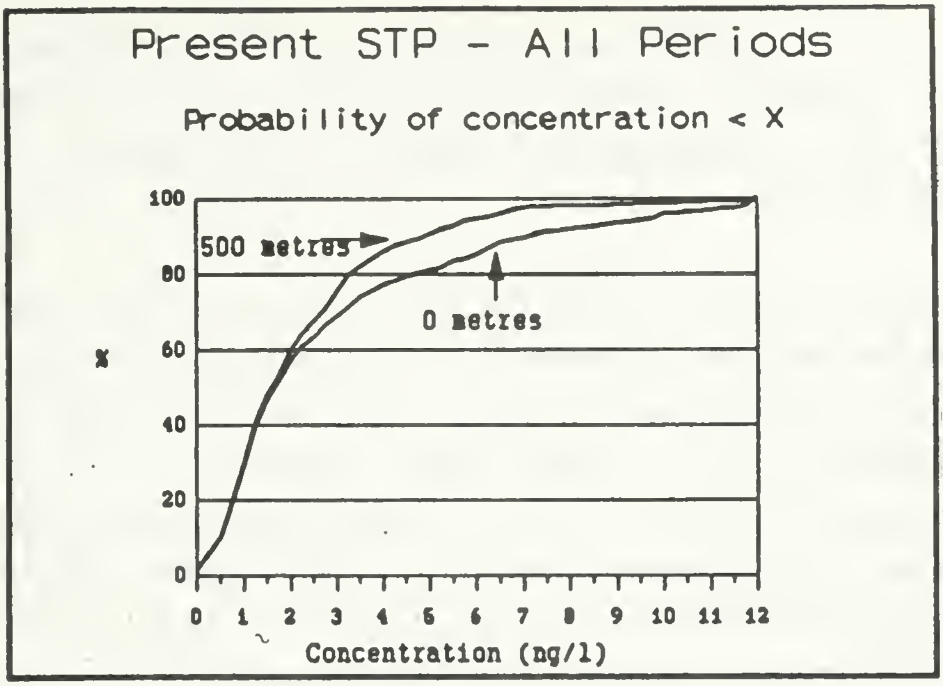


FIGURE 4.9:
Probability of observing a contaminant concentration with a loading of 100 grams per day at the present Toronto Main STP outfall.

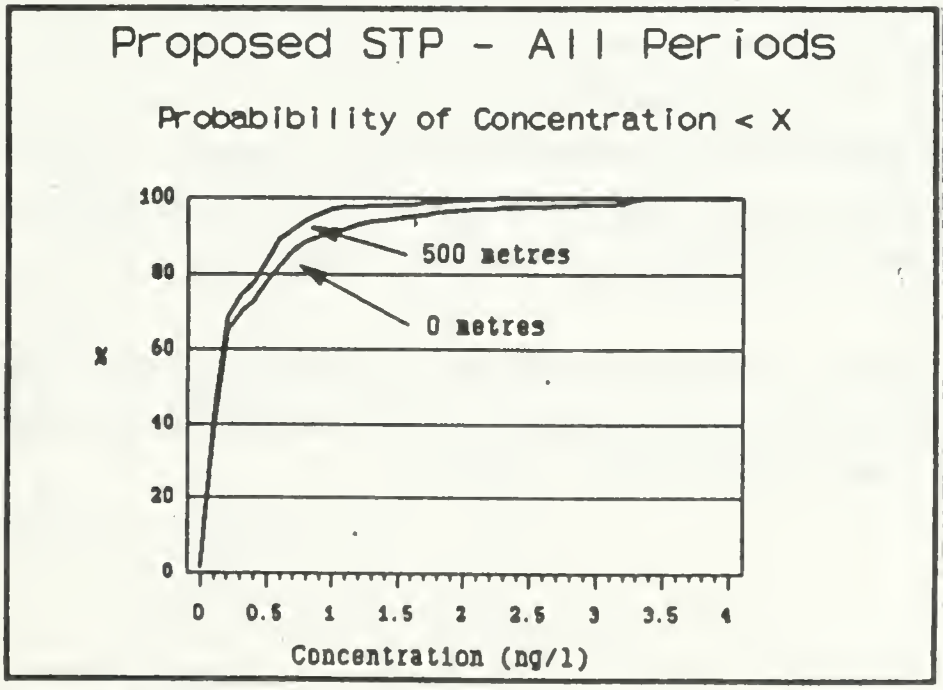


FIGURE 4.10:
Probability of observing a contaminant concentration with a loading of 100 grams per day at the proposed offshore Toronto Main STP outfall.

zenes which have significant local input, the cleanup of the Toronto Waterfront requires a whole-lake approach. Contaminants from other sources, such as from the Niagara River, must be reduced to obtain a significant reduction in toxic contaminant concentrations in the Toronto Waterfront.

As conservative behavior was assumed over a distance of 500 m from the outfall, the scenario described above is appropriate for deriving effluent limits for parameters currently in exceedence of PWQO near the outfall. It is assumed that the predicted concentration at zero and 500 m from the outfall is directly proportional to the loading applied. Using this assumption and the same (objective - background) values given in Table 4.2, the model is used inversely to estimate an allowable load; i.e. if it is desired to achieve a concentration of 8.0 μg/L 95% of the time 500 m from the outfall, then the maximum allowable loading is 100 kg/d (Figure 4.9). As before, these allowable loadings are compared to the observed 95 percentile loadings to to derive effluent limits. The results are given in Table 4.6.

At 500 m from the present outfall, this model predicts that the present loadings should satisfy effluent requirements for iron, copper, PCB and lindane. Observed data for this distance in 1987 indicate that all samples meet PWQO for iron and copper with the exception of one iron sample; thus the predictions are consistent with observations. Lindane was not measured at this distance in either survey year. No PCBs were measured using ultra- trace methodology at this distance. Required reductions for other parameters range from 24% for cadmium to 90% for total phosphorus and 98% for chlorine residual.

At 500 m from the proposed outfall, all parameters are predicted to be in compliance, except for total phosphorus (17% reduction required), PCBs (50% reduction required) and chlorine residual (86% reduction required).

TABLE 4.6: EFFLUENT LIMITS BASED ON FATE AND TRANSPORT MODEL

PARAMETER	Observed 1987 95% ile Load kg/d	Existing Outfall Location 0m Allowable Load kg/d	Existing Outfall Location 0m % Reduction Required	Existing Outfall Location 500 m Allowable Load kg/d	Existing Outfall Location 500 m % Reduction Required	Proposed Outfall Location 0m Allowable Load kg/d	Proposed Outfall Location 0m % Reduction Required	Proposed Outfall Location 500 m Allowable Load kg/d	Proposed Outfall Location 500 m % Reduction Required
NH_3 (worst case)	3.2×10^4	8.7×10^3	73	1.25×10^4	61	3.0×10^4	6	5.0×10^4	0
Total P (guideline)	1200	87	93	125	90	300	75	500	58
Fe	2000	2400	17	3500	0	8400	0	1.4×10^4	0
Cu	40	35	13	50	0	120	0	200	0
Cd	3.3*	1.7	48	2.5	24	6	0	10	0
Lindane (g/d)	65	78	0	110	0	270	0	450	0
Cl_2 residual	1.4×10^3	17	98.8	25	98.2	61	96	100	93
PCB (g/d)	40	3.5	91	5	88	12	70	20	50

Note * - 1986 data

However, it must be kept in mind that the PCB dilutions were calculated with an average background concentration of 0.6 ng/L, which at times may be as high as 1 ng/L (i.e., the PWQO). Therefore, the required loading reduction at the outfall location may be as high as 100%; furthermore, as Halfon (1990) has stated, contaminant loadings from other sources such as Niagara River and atmospheric must be reduced in order to achieve the full benefit from local abatement measures.

4.7 Consensus

The allowable loads calculated in the previous sections are the load for which the defined objective (or guideline) will be satisfied for a specified fraction of the time, given the statistical variability of the effluent quality. In performing these calculations, recommended allowable loads were based on a compliance target of 95%. In other words, receiving water quality at the edge of the mixing zone would only be allowed to be out of compliance 5% of the time. A more stringent compliance target requires a more restrictive allowed load.

In the previous sections, several methodologies were used in deriving effluent limits. Plume tracking results combined with inferences based on interparameter correlations allow a semi-empirical calculation of allowable loads. Modelling techniques including a simple dilution model as well as a more complex fate and transport model provide theoretical calculations which also allow for an estimate of allowable loads for the proposed offshore outfall location.

Tables 4.7 and 4.8 present summaries of load allocations for zero and 500 m radius mixing zones respectively, as calculated by the methods described in the previous sections. These are based on a target of 95% compliance with PWQO at the stated distances from the outfall diffuser.

It is observed that the simple dilution model predicts more stringent limits than the fate model; the plume track results are intermediate. As discussed in Section 4.4, the plume

Table 4.7: **Summary of Load allocations (Kg/d) for 95% PWQO compliance target, based on zero mixing zone calculated by different methods**

		Existing Outfall									Proposed Outfall					
		Dilution Model			Plume Track			Fate Model			Dilution Model			Fate Model		
Parameter	Observed 1987 95%ile Load (kg/d)	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd
Ammonia	$3.2x10^4$	2.3 mg/L	2200	93	4.3 mg/L	$4.1x10^3$	88	9.1 mg/L	$8.7x10^3$	73	23.5 mg/L	$2.3x10^4$	28	31 mg/L	$3.0x10^4$	6
Chlorine res.	$1.4x10^3$	4.8	4.4	99.7	5.8	5.4	99.6	18	17	98.8	47	45	97	64	61	96
Total Phosphorus	$1.2x10^3$	24	23	98	46	44	96	91	87	93	245	235	80	310	300	75
Iron	$2.0x10^3$	660	630	69	1030	990	51	2500	2400	17	6600	6300	0	8700	8400	0
Copper	40	10	10	75	15	14	65	36	35	13	95	91	0	125	120	0
Cadmium	3.3*	0.46	0.44	87	0.7	0.7	79	1.8	1.7	48	4.7	4.5	0	6	6	0
Lindane	65**	22	21	68	33	32	51	81	78	0	210	200	0	280	270	0
PCB	40**	1.5	1.4	97	2.0	1.9	95	3.6	3.5	91	10	10	75	13	12	70

Note: *Dilution model figures are from table 4.2*
Plume track figures are from table 4.5
Fate model figures are from table 4.6; concentrations back-calculated based on average flow of 960 x 10^3 m^3/d

* 1986 data
** Lindane and PCB loadings are in g/d; concentrations in ng/L

Table 4.8: **Summary of Load allocations (Kg/d) for 95% PWQO compliance target, based on 500 m radius mixing zone calculated by different methods**

		Existing Outfall									Proposed Outfall					
		Dilution Model			Plume Track			Fate Model			Dilution Model			Fate Model		
Parameter	Observed1987 95%ile Load(kg/d)	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd	Outfall concn µg/L	Allowable Load Kg/d	% redn req'd
Ammonia	$3.2x10^4$	4.3 mg/L	4.1 $x10^3$	87	8.9 mg/L	$6.6x10^3$	79	13 mg/L	$1.25X10^4$	61	43 mg/L	$4.1x10^4$	0	52 mg/L	$5.0x10^4$	0
Chlorine res.	$1.4x10^3$	8.6	8.3	99.4	16	15	98.9	26	25	98.2	86	63	94	104	100	93
Total Phosphorus	$1.2x10^3$	53	51	96	68	65	95	130	125	90	440	420	65	520	500	58
Iron	$2.0x10^3$	1220	$1.16x10^3$	42	1630	$1.56x10^3$	22	3650	$3.5X10^3$	0	12000	$1.2x10^4$	0	14600	$1.4x10^4$	0
Copper	40	18	17	58	24	23	43	52	50	0	172	165	0	208	200	0
Cadmium	3.3*	0.86	0.83	75	1.2	1.1	67	2.6	2.5	24	8.6	8.3	0	11	10	0
Lindane	65**	40	38	42	53	51	22	115	110	0	390	370	0	470	450	0
PCB	40**	2.3	2.2	95	2.9	2.8	93	5	5	88	18	17	58	21	20	50

Note: *Dilution model figures are from table 4.2*
Plume track figures are from table 4.5
Fate model figures are from table 4.6; concentrations back-calculated based on average flow of 960 x 10^3 m^3/d

* *1986 data*
** *Lindane and PCB loadings are in g/d; concentrations in ng/L*

tracking results are subject to inherent variability as a consequence of physical conditions which change from one day to the next - e.g. from stagnation to average currents to jetting, as well as rapidspatial variations in concentration in the initial mixing zone within tens of metres from the diffuser. Data in the table represent average to jetting currents.

Predictions based on the dilution model are also sensitive to the choice of physical parameters such as current speed, mixing depth and total water depth (Table 4.1). The effluent requirements calculated in Tables 4.2, 4.7 and 4.8 represent average currents (0.1 m/s); the assumption of jetting would result in higher initial dilution but poorer far-field dilution. Observed initial dilutions (Tables 3.16, 4.3 and 4.4) do not support this premise of higher initial dilution under jetting conditions; an improved model of initial dilution is to be developed in the near future (B. Kohli, pers. comm.). Therefore, the estimates of initial dilution at the proposed outfall location can only be considered as a first approximation to the actual dilutions which might be achieved at this location.

The more complex fate and transport model predicts less stringent reductions than that predicted by either of the other two methods. This is particularly true for the heavy metals and lindane. The major limitation of this model is the size of grid square (500 m) used; therefore, the "zero" mixing zone results actually represent an average concentration between 0 and 250 m radius of the outfall. Consequently, the allowable loadings in Tables 4.6 and 4.7 more accurately represent predictions for a 250 m radius of mixing zone. Results for 500 m similarly represent an average of conditions between 250 and 750 m radius; however it should be noted that observed data in 1987 at 500 m (stations 2877 and 2878) showed compliance with PWQO for all heavy metal data except one iron sample; lindane and PCBs were not measured at this distance.

Predictions of dilution and consequent allowable loadings at the proposed outfall from the fate model, appear to be unrealistically high compared to the dilution model. However, predictions based on this model are strongly dependent upon the RAND model currents used as input; it is known that these predictions may not be as reliable at locations close

to the model boundary such as this one. These predictions therefore, do not appear to be defensible without further validation. It is suggested that further sampling for the parameters in question be undertaken, in order to validate the model predictions. This should include simultaneous sampling of the effluent, and in-lake at distances of 0 and 500 m from the outfall in the direction of current movement. Sampling should be done on an intensive basis, for example, daily for one week in each month to obtain a statistically significant number of data points. See also Section 6.2 for further sampling recommendations.

5.0 CRITIQUE OF ASSESSMENT PROCEDURES

In this report, we have illustrated various methods of deriving dilution contours and compliance zones from water quality data. Compliance (or non-compliance) zones, and effluent limits corresponding to specific compliance zones, are based directly on a dilution envelope model. Three types of dilution envelope modelling have been presented:

1. A simple graphical approach (Sections 3.2.2, 3.2.3 and 4.4);

2. A theoretical approach involving calculation of initial mixing at the end of pipe from flow rate, water depth and relative plume stability, combined with far-field dilution from an unsteady state flow model (section 4.1); and

3. A combination of an unsteady state hydrodynamic model driven by current meter and wind data with a pollutant transport model (Section 4.5).

In support of the above, an extensive data base has been gathered, involving effluent quality at the Main STP, as well as Lake Ontario water quality in the vicinity of the Main STP and across the entire Toronto Waterfront.

A fourth approach, not illustrated here, would make use of concentration and current velocity data in all directions, based on drogue cluster releases. With this information, a more sophisticated dilution envelope model can be constructed, which changes with current conditions. The information gathered in 1986 (Section 4.4; Table 4.4) was useful as an adjunct to the plume tracking data gathered in 1987 but was inadequate for full utilization of this approach.

Some of the problems inherent in the modelling techniques have already been discussed in Section 4.6. These models are only as good as the data base which supports them, and an adequate description of the effluent and receiving water quality at various scales of temporal and spatial resolution is vital to the success of the project.

The techniques used in this study which lead to the effluent limit setting approaches described in Section 4 have been summarized in Table 5.1. A few comments follow:

As the effluent loading shows considerable temporal variability both at short- and long-time scales, an integrated approach to address this variability and its impact on the nearshore zone is important in establishing initial and far-field dilution rates. This would be best achieved by simultaneous time-sequential sampling of both the effluent and the lake adjacent to the outfall (station 1419), combined with plume tracking and tracking of drogue clusters. Several days of application of this technique in different seasons would help to cover seasonal changes combined with variability in the current climate (e.g. stagnation, jetting, variable current directions). The largest drawback to this approach is that it is extremely manpower intensive as separate crews are required for each component undertaken at the same time.

If surveys of the above type are properly undertaken, they can be augmented with small-scale surveys (fixed grid and effluent monitoring) which would provide seasonal information on a year-round basis. It would be helpful to have winter data for parameters such as ammonia, which nitrifies at a much slower rate and therefore has greater capacity to exceed PWQO, despite the lower unionized fraction of total ammonia at lower temperatures.

Given practical data limitations, a combination of plume tracking (including on-board measurement of several key parameters) with one or more modelling techniques is likely the most useful approach to setting effluent limits with a reasonable level of confidence.

TABLE 5.1: UTILITY OF VARIOUS TECHNIQUES FOR ESTABLISHING EFFLUENT LIMITS

Technique	Usefulness in Limit Derivation	Level of Effort Expended in This Study
EFFLUENT CHEMISTRY:		
Sequential sampling	Essential	More than adequate
Daily sampling	Essential	Adequate
Seasonal sampling	Supportive	Less than adequate
AMBIENT WATER CHEMISTRY:		
Sequential sampling at outfall	Highly supportive	Less than adequate
Plume tracking	Essential	Less than adequate
Fixed-grid sampling	Supportive	More than adequate
PHYSICAL MONITORING:		
Drogue tracking	Highly supportive	Less than adequate
Current metering	Supportive	Adequate
Hydrodynamic modelling	Supportive	Adequate

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Calculations based on two models (dilution model and fate model), as well as on field-measured plume tracking data, have been used to estimate the extent of loading reductions required to meet Provincial Water Quality Objectives at various locations. It should be noted that these are only model estimates; the final model for loading reduction calculations has not been selected, nor has the allowable distance from the outfall been finalized.

1. It is important that site-specific water quality based effluent limits be developed in accordance with the MISA water quality track. This is evident due to difference in effluent reductions required for the present and proposed outfalls.

2. Based on dilution model results (more conservative than the fate model), it is evident that dechlorination of the final effluent will be necessary in order to meet Provincial Water Quality Objectives (PWQO) in the receiving water.

   - At the existing outfall location, in order to meet PWQO at the end of the pipe 95% of the time, residual chlorine levels in the final effluent must be reduced by 99.6% to 5 μg/L. In order to meet PWQO at the edge of a 500m mixing zone 95% of the time, final effluent chlorine levels must be reduced by 99% to 16 μg/L.

   - At the proposed offshore outfall location, in order to meet PWQO at the end of the pipe 95% of the time, chlorine levels in the effluent must be reduced by 97% to 47 μg/L. In order to meet PWQO at the edge of a 500m mixing zone 95% of the time, chlorine levels in the effluent must be reduced by 94% to 86 μg/L.

3. Ammonia removal in the final effluent will be necessary to meet PWQO in the receiving water under summer conditions.

- At the existing outfall, in order to meet PWQO at the end of the pipe 95% of the time, ammonia levels in the final effluent must be reduced by 88 to 93% to 2.3 - 4.3 mg/L. Similarly, for the edge of a 500m mixing zone, the levels must be reduced by 79 to 87% to 4.3-6.9 mg/L.

- At the proposed offshore location, in order to meet PWQO at the end of the pipe 95% of the time, ammonia levels in the final effluent must be reduced by 28% to 23.5 mg/L. However, no reduction in effluent ammonia levels is required to meet PWQO 95% of the time at the edge of a 500m mixing zone.

4. Enhanced phosphorus removal (tertiary treatment) of the final effluent will be necessary to meet the Provincial Water Quality Guidelines (PWQG) for prevention of nuisance algal growth.

- At the existing outfall location, in order to meet the PWQG at the end of the pipe 95% of the time, final effluent total phosphorus levels must be reduced by 96-98% to 24-46 μg/L. Similarly for the edge of a 500m mixing zone, the level must be reduced by 95% to 68 μg/L. Based on dilution model predictions, distances of 17 and 35 km are required for dilution to PWQG of effluent concentrations of 0.5 and 1.0 mg/L, respectively.

- At the proposed offshore outfall location, in order to meet PWQG 95% of the time at the end of the pipe, final effluent total phosphorus levels must be reduced by 80% to 245 μg/L. Similarly for a 500m mixing zone, the levels must be reduced by 65% to 440 μg/L. Based on dilution model predictions, distances of 0.7 and 3.6 km are required for dilution to PWQG of effluent concentrations of 0.5 and 1.0 mg/L, respectively.

5. At the existing outfall location, loading reductions of heavy metals and organic contaminants will be necessary in order to meet PWQO in the receiving water. However, improved dilution characteristics at the proposed offshore outfall location will allow PWQO for these parameters to be achieved after initial dilution.

- In order to meet PWQO for copper at the end of the pipe 95% of the time at the existing outfall location, the final effluent level must be reduced by 65-75% to 10-15 μg/L. Similarly, for the edge of a 500m mixing zone, the required reduction is 43-58% to 18-24 μg/L. Required reductions for other metals and most organics such as lindane are lower and should be achieved if the above reductions are met.

- In the case of PCBs, loading reductions of 93 to 95% are estimated for zero and 500 m mixing zones, based on average observed background levels. However, the highest background PCB levels are similar to the PWQO of 1 ng/L; hence required loading reductions may be as high as 100% for either outfall location.

6. Both plume tracking and modelling studies show that higher current speeds result in reduced longitudinal mixing of the effluent plume. Under such conditions, increased surface conductivity and ammonia concentrations were observed at distances up to 6 km from the Main STP outfall.

7. The following general conclusions summarize the most important water quality characteristics of the Main STP effluent and Lake Ontario in the vicinity of the outfall.

   a. Ammonia and chlorine approach the thresholds of acute toxicity to aquatic biota at the Main STP outfall, and are most likely responsible for any acute

toxicity observed (Flood, 1990, Neville, 1990). Acute toxicity is not likely beyond a 500 m radius of the outfall.

b. Total ammonia averages approximately 7 mg/L at the outfall (near the surface), and the PWQO for unionized ammonia is exceeded in approximately 75% of samples. Ammonia concentration declines rapidly to about 0.1 mg/L (20% exceedence) at a distance of 3 km south of the outfall (background is less than 0.04 mg/L).

c. Free chlorine averages approximately 330 μg/L at the outfall (near the surface) from June through September when chlorination occurs in the Main STP. The PWQO for free chlorine is exceeded in approximately 70% of samples over this period. The concentration declines rapidly to about 20 μg/L (still 70% exceedence) 3 km south of the outfall (background is zero).

d. Total phosphorus averages approximately 0.2 mg/L at the outfall (near the surface), and the PWQO is almost always exceeded here. Phosphorus declines to about 0.03 mg/L (30% exceedence) 3 km south of the outfall (background is about 0.02 mg/L and 15% exceedence).

e. A slight pH depression at the outfall (pH 7.3 compared to 8.0 and above at surrounding stations) will slightly favour ionization of ammonia thereby suppressing ammonia toxicity to some extent.

f. Heavy metals exceeding PWQOs include iron (77%), copper (38%) and cadmium (31%). Metal concentrations at the outfall near the surface average 0.47 mg/L, 0.006 mg/L and 0.0005 mg/L, respectively, approaching background within 3 km south of the outfall.

g. Organochlorine pesticides lindane, heptachlor and dieldrin occasionally exceed PWQOs at the outfall; however, average concentrations do not approach even chronic toxicity thresholds.

h. Main STP effluent generally rises rapidly to the surface, resulting in a surface maximum for most contaminants. This pattern persists at stations within about 1,000 m of the outfall.

i. Spatial pattern analysis of the Toronto Waterfront indicates a strong water quality impact at the Main STP outfall, moderate impact at the Humber Bay STP outfall and Coatsworth Cut, and lesser impact zones near the Don River and Rouge River mouths and in Toronto Harbour. Long-term temporal trends at the Main STP outfall and Don River mouth also suggest ongoing degradation of water quality.

j. Comparison of 1986 and 1987 water quality suggests slightly higher concentrations of most metals near the outfall in 1987; however, only manganese and nickel increases were statistically significant. Free chlorine discharge was nominally lower in 1987, though the difference was not significant, while ammonia and phosphorus concentrations at the outfall were similar between years.

k. Potential surrogates for trace metals include suspended solids and total phosphorus in Main STP effluent, and conductivity and suspended solids in receiving water. In the Main STP effluent, the data collected were inadequate to define potential surrogates for organic compounds measured at ultra-trace levels. In receiving water, total phosphorus was found to be a potential surrogate for many of the ultra-trace organic parameters during June and August 1987. Total Kjeldahl nitrogen in June, and conductivity, total filtered

residue and suspended solids in August also showed some usefulness as surrogates. No potential surrogates were found in October 1987.

l. Total ammonia in Main STP effluent shows a consistent pattern of increase over the course of the day from about 10:00 a.m. to 5:00 p.m. Phosphorus is more tightly controlled, though extremes tend to occur later in the day. Flow may either increase or decrease over the course of the day. Both ammonia and flow exhibit large day-to-day variations.

m. Long-term prediction of daily average outfall concentrations may be possible with some success based on daily average concentrations in the Main STP effluent. However, short-term prediction based on instantaneous effluent measurements will require a hydrodynamic model which explicitly accounts for receiving water conditions. Existing data are inadequate for development of these predictive relationships.

6.2 Recommendations

Environmental survey design and data handling strategies should be derived from study objectives. Pilot study objectives appear to fall into four categories:

1. Description and prediction of short-term (daily) temporal patterns in receiving water quality near point sources.
2. Description and prediction of long-term (seasonal) temporal patterns in receiving water quality near point sources.
3. Description of spatial patterns over the waterfront (and correspondence with known discharges).
4. Compliance evaluation of effluent discharges and adjacent receiving waters with respect to effluent and receiving water objectives.

The data needs, optimum sampling designs and data handling procedures differ for each of these objectives. Any design must consider that, unlike rivers where the downstream direction is simply defined, for a lake discharge, 'downstream' varies in time and may not be definable at some times. There are also transition periods when downstream is changing in direction. Furthermore, unlike rivers, the effects of density stratification for lake discharges can persist for considerable distances from the outfall. The following design principles, data gathering and data handling procedures should be applied:

1a. For short-term (i.e. daily cycle) description and predictive model development, the sampling interval should be short (on the order of hours), both in the source effluent and the adjacent receiving water. The effluent and receiving water sampling times should match as closely as possible. A specific design (i.e. random, stratified random, systematic) should be chosen. Gilbert (1987) discusses the advantages and disadvantages of each design.

1b. Because conductivity has been found to be a good surrogate parameter for metals and some ultra-trace organics in the receiving water, recording conductivity meters could be mounted on floats and located near the outfall at various distances from the outfall, as well as in the effluent discharge manhole. This would provide complete short-term data on the variabilities in the discharge and the receiving water, and ensure a perfectly matched 'real time' record.

1c. In order to provide better identification of surrogate parameters for toxic organics in the effluent, a more intensive sampling design involving properly matched samples for all parameters is required. This should include as large a range of effluent conditions as possible, and include improved techniques for handling samples high in suspended solids in order that all samples be properly representative of effluent conditions.

1d. Empirical velocity data for the period of sampling would greatly enhance the ability to develop predictive models. This must be obtained by releasing a <u>cluster</u> of drogues and following the position of each drogue over time.

1e. Sampling periods need only cover a few days, but each period should represent a particular set of well-documented current, weather and wind conditions. With sufficient data, dynamic models (such as the Rand Model) can be used for receiving water predictions based on time of day and prevailing conditions.

2. For long-term description and predictive model development, the primary sampling units are days. Again, a specific sampling design should be chosen (see Gilbert, 1987). Steps should be taken to limit short-term (i.e. time of day) temporal sampling bias between days, especially near a source with a known or suspected daily cycle. Daily (24-h) composite effluent sampling, supported by more frequent (hourly to 3 h) grab sampling will help to define the temporal cycle and its probable error limit. The same sampling schedule should be used for source and adjacent receiving water.

3. For description of broad spatial patterns, every effort should be made to limit temporal sampling bias between regions. All stations should be sampled on each survey, preferably in a randomized sequence.

4. The vertical distribution of samples with depth should follow a specific sampling design. The random design is least efficient. A stratified random design is more efficient if strata are easily recognized (e.g., samples identified as in-plume, above, or below), otherwise a systematic design (fixed depths) is preferred. Arbitrary pooling of depths for statistical summary is unwise when depth trends are known to exist in receiving water, and no particular sampling design has been followed.

5. Any descriptive statistical inference (e.g. mean or variance estimation) requires that the sampling units, population boundaries (i.e. spatial and temporal domain) and

sampling design be defined. For example, replicate analyses on a single sample are not primary sampling units, but represent sub-units in a two-stage sampling design. To use them as primary units, when replication is unequal among the primary units of the population, will bias both the mean and variance estimates (Gilbert, 1987). Likewise, field replicates (taken at essentially the same spatial point and time) are not primary sampling units in a population of broader temporal or spatial domain.

6. Preferred methods of handling censored (i.e. less than detection) data in mean and variance estimations will depend on the study objectives. For compliance purposes where a mean is compared to a water quality guideline, a conservative assumption of 'face value' concentration in each sample is probably preferable. For descriptive purposes where a most likely estimate is desired, Cohen's (1961) maximum likelihood method is probably preferable. Each element of a water quality summation should be related to one or the other (not both) of these purposes.

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APPENDIX 1

WATER QUALITY STATISTICAL SUMMARIES
FOR TOXICITY TEST PERIODS

CONVENTIONALS

DURING TOXICITY TESTS

1986

CONDUCTIVITY (µmho/cm) AT SURFACE AND BOTTOM, 12-14 AUGUST, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	14	508	520	44	457	578
1431	10	365	343	53	311	432
1432	10	321	313	23	308	365
1433	8	421	452	73	305	476
1434	10	385	344	69	321	467
1536	6	313	315	4	308	315
2029	4	305	305	6	299	310
Bottom or depth of turbidity max. (4-20 m)						
1419	14	399	336	99	313	579
1431	10	317	313	16	300	344
1432	9	311	310	7	305	323
1433	8	310	310	5	305	317
1434	8	316	315	14	304	332
1536	1	309	309	-	309	309
2029	2	307	307	3	305	309

CONDUCTIVITY (µmho/cm) AT SURFACE, MID-DEPTH AND BOTTOM, 08-10 SEPTEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	16	547	559	47	474	616
1431	12	438	453	54	347	506
1432	10	313	313	2	311	317
1433	10	443	464	118	313	566
1434	10	314	314	2	311	318
1536	3	317	315	4	315	323
2029	2	317	317	5	313	321
Mid-depth (3 m)						
1419	8	411	423	63	321	486
1431	6	335	330	20	314	369
1432	5	313	313	1	311	315
1433	4	329	324	20	313	355
1434	5	312	313	1	310	313
Bottom or depth of turbidity max. (4-20 m)						
1419	16	367	362	45	315	456
1431	12	315	314	3	312	322
1432	9	312	312	1	312	314
1433	10	313	313	1	311	314
1434	10	313	313	1	312	315
1536	1	314	314	-	314	314
2029	2	313	313	1	312	313

CONDUCTIVITY (µmho/cm) AT SURFACE, MID-DEPTH AND BOTTOM, 04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	18	502	499	26	461	541
1431	12	398	415	48	335	455
1432	12	353	347	46	308	408
1433	12	414	434	79	314	524
1434	12	442	479	91	321	543
1536	3	308	310	2	305	310
2029	2	309	309	1	308	310
Mid-depth (3 m)						
1419	9	368	348	40	321	422
1431	6	361	364	31	326	397
1432	6	330	315	30	309	383
1433	6	346	337	34	314	391
1434	6	351	352	41	310	393
Bottom or depth of turbidity max. (4-20 m)						
1419	18	322	321	13	308	354
1431	12	329	324	19	310	367
1432	12	313	314	4	308	321
1433	12	316	316	6	308	325
1434	12	315	317	5	308	322
1536	3	308	309	1	307	310
2029	2	309	309	0	309	309

WATER TEMPERATURE (°C) AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	14	14.6	15.9	2.0	12.2	16.7
1431	10	13.3	11.6	3.4	9.8	17.2
1432	10	12.2	10.8	3.6	8.6	16.4
1433	8	12.4	11.0	3.0	10.2	17.1
1434	10	12.9	10.5	3.4	10.0	16.9
1536	6	15.6	16.1	1.3	13.9	16.7
2029	4	14.6	14.6	5.1	10.1	19.0
Bottom or depth of turbidity max. (4-20 m)						
1419	14	11.2	11.6	3.2	7.6	16.9
1431	10	8.8	8.4	2.5	5.9	12.2
1432	9	8.5	7.6	3.1	5.8	12.6
1433	8	7.8	6.8	2.6	5.9	11.8
1434	8	9.3	9.2	3.5	6.0	12.8
1536	1	8.9	8.9	-	8.9	8.9
2029	2	6.9	6.9	1.1	6.1	7.7

WATER TEMPERATURE (°C) AT SURFACE, MID-DEPTH AND BOTTOM, 08-10 SEPTEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	16	13.1	12.6	2.2	9.8	17.3
1431	12	11.4	10.3	2.4	9.0	14.7
1432	10	8.1	7.1	3.0	5.7	13.3
1433	10	10.6	12.4	4.1	6.0	15.6
1434	10	7.9	6.8	2.4	6.0	12.3
1536	3	13.7	13.4	0.5	13.4	14.3
2029	2	7.5	7.5	1.2	6.6	8.3
Mid-depth (3 m)						
1419	8	10.4	10.3	2.7	6.8	14.6
1431	6	9.3	7.6	3.3	6.3	14.6
1432	5	7.6	6.6	2.9	5.7	12.6
1433	4	6.8	6.9	1.1	5.8	7.8
1434	5	7.6	6.7	2.6	6.0	12.1
Bottom or depth of turbidity max. (4-20 m)						
1419	16	9.2	8.8	2.6	6.5	13.2
1431	12	8.2	6.1	3.3	6.0	13.5
1432	9	6.6	6.2	2.1	5.5	12.1
1433	10	7.4	6.5	2.6	5.8	12.3
1434	10	7.2	5.8	2.6	5.8	12.0
1536	1	11.0	11.0	-	11.0	11.0
2029	2	6.2	6.2	0.8	5.6	6.7

WATER TEMPERATURE (°C) AT SURFACE, MID-DEPTH AND BOTTOM, 04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	18	11.6	11.6	0.5	11.0	12.4
1431	12	10.1	10.2	0.8	9.0	11.2
1432	12	9.3	9.3	0.7	8.6	10.3
1433	12	10.3	10.8	1.2	8.7	11.9
1434	12	10.9	11.3	1.4	8.9	12.4
1536	3	9.3	9.3	0.3	9.1	9.6
2029	2	9.0	9.0	0.1	8.9	9.0
Mid-depth (3 m)						
1419	9	9.6	9.3	0.6	8.8	10.6
1431	6	9.6	9.6	0.8	8.7	10.4
1432	6	8.9	8.7	0.5	8.5	9.7
1433	6	9.3	9.5	0.5	8.7	9.8
1434	6	9.3	9.3	0.6	8.7	10.0
Bottom or depth of turbidity max. (4-20 m)						
1419	18	8.8	8.8	0.3	8.6	9.5
1431	12	8.8	8.8	0.2	8.6	9.1
1432	12	8.7	8.6	0.3	8.5	9.4
1433	12	8.7	8.6	0.1	8.6	8.8
1434	12	8.7	8.7	0.1	8.6	8.8
1536	3	8.7	9.2	1.2	7.3	9.5
2029	2	9.0	9.0	0.1	8.9	9.0

PH AT SURFACE AND BOTTOM,
12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface						
1419	14	7.88	7.90	0.17	7.53	8.14
1431	12	8.01	8.16	0.53	6.33	8.26
1432	11	8.27	8.25	0.06	8.18	8.38
1433	11	8.08	8.05	0.13	7.89	8.27
1434	11	8.22	8.23	0.11	7.94	8.38
1536	4	8.32	8.31	0.03	8.28	8.36
2029	4	8.32	8.28	0.11	8.23	8.47
Bottom or depth of turbidity max. (4-20 m)						
1419	14	7.96	7.93	0.22	7.65	8.32
1431	12	8.24	8.24	0.06	8.10	8.30
1432	12	8.26	8.28	0.06	8.15	8.33
1433	12	8.28	8.28	0.06	8.18	8.38
1434	10	8.28	8.24	0.08	8.03	8.34
1536	2	8.26	8.26	0.01	8.25	8.27
2029	4	8.24	8.28	0.08	8.12	8.31

pH AT SURFACE AND BOTTOM,
04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	18	7.84	7.84	0.16	7.54	8.17
1431	12	8.07	8.10	0.08	7.93	8.17
1432	12	8.17	8.22	0.16	7.94	8.37
1433	12	8.09	8.06	0.17	7.91	8.39
1434	12	7.99	7.92	0.19	7.79	8.25
1536	3	8.38	8.40	0.04	8.33	8.41
2029	2	8.30	8.30	0.04	8.27	8.33
Bottom or depth of turbidity max. (4-20 m)						
1419	18	8.22	8.26	0.24	7.58	8.47
1431	12	8.16	8.18	0.09	7.98	8.28
1432	12	8.23	8.24	0.05	8.12	8.28
1433	12	8.24	8.26	0.11	7.98	8.39
1434	12	8.23	8.24	0.09	8.12	8.38
1536	3	8.33	8.34	0.07	8.26	8.39
2029	2	8.30	8.30	0.01	8.29	8.31

FIELD-MEASURED FREE CHLORINE (µg/L) AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface								
1419	14	551	580	145	340	740	0	14
1431	10	82	58	98	0.0	260	2	8
1432	10	2	0.0	2	0.0	4	6	4
1433	12	159	7	230	0.0	500	6	6
1434	11	65	42	62	8	164	0	11
1536	6	0.0	0.0	0.0	0.0	0.0	6	0
2029	6	0.0	0.0	0.0	0.0	0.0	6	0
Bottom or depth of turbidity max. (4-20 m)								
1419	14	377	560	317	7	680	0	14
1431	10	16	6	28	0	68	4	6
1432	12	19	0	37	0	96	8	4
1433	12	3	0	5.5	0	14	8	4
1434	11	7.8	0	12	0	30	7	4
1536	4	0.0	0.0	0.0	0.0	0.0	4	0.0
2029	4	0.0	0.0	0.0	0.0	0.0	4	0.0

[1] Number of samples at or below the detection limit (assumed to be zero)
[2] Number of samples above the Provincial Water Quality Objective (PWQO)

CHLORINE RESIDUAL (µg/L) AT SURFACE, MID-DEPTH AND BOTTOM, 08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface (0-1 m)								
1419	16	1028.0	520.0	1722.5	44.0	5400.0	0	16
1431	12	420.7	268.0	492.8	40.0	1420.0	0	12
1432	8	0.0	0.0	0.0	0.0	0.0	8	0
1433	10	91.2	46.0	143.5	0.0	360.0	4	6
1434	8	0.0	0.0	0.0	0.0	0.0	8	0
1536	3	0.0	0.0	0.0	0.0	0.0	3	0
2029	2	10.0	10.0	14.2	0.0	20.0	1	1
Mid-depth (3 m)								
1419	8	182.3	84.0	208.3	0.0	440.0	2	6
1431	6	86.0	55.0	112.4	0.0	300.0	1	5
1432	5	0.0	0.0	0.0	0.0	0.0	5	0
1433	5	22.0	0.0	35.0	0.0	80.0	3	2
1434	4	0.0	0.0	0.0	0.0	0.0	4	0
Bottom or depth of turbidity max. (4-20 m)								
1419	14	137.4	160.0	116.2	0.0	280.0	3	11
1431	12	0.0	0.0	0.0	0.0	0.0	12	0
1432	9	0.0	0.0	0.0	0.0	0.0	9	0
1433	10	0.0	0.0	0.0	0.0	0.0	10	0
1434	10	0.0	0.0	0.0	0.0	0.0	10	0
1536	1	0.0	0.0	0.0	0.0	0.0	1	0
2029	2	0.0	0.0	0.0	0.0	0.0	2	0

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO).

FIELD-MEASURED TOTAL AMMONIA (mg/L)
AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	14	7.30	7.7	0.99	5.02	8.16	0	14	14
1431	12	2.50	1.53	2.49	0.0	6.56	2	9	12
1432	12	0.48	0.11	0.78	0.0	2.12	2	2	9
1433	12	4.01	3.40	4.15	0.0	9.64	2	6	7
1434	11	1.92	1.98	1.81	0.0	4.94	1	6	10
1536	6	0.017	0.012	0.02	0.0	0.042	3	0	5
2029	4	0.011	0.0	0.020	0.0	0.05	2	0	2
Bottom or depth of turbidity max. (4-20 m)									
1419	14	4.40	5.25	2.46	0.05	7.18	0	12	14
1431	12	0.38	0.10	0.51	0.0	1.36	2	4	10
1432	12	0.23	0.17	0.23	0.0	0.55	2	0	9
1433	12	0.37	0.14	0.58	0.0	1.86	2	2	8
1434	11	0.63	0.05	0.85	0.0	2.76	1	5	8
1536	4	0.007	0.002	0.009	0.0	0.020	1	0	3
2029	2	0.018	0.007	0.027	0.014	0.058	0	0	2

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO).
[3] Number of samples compared to PWQO (temperature and pH required)

FIELD MEASURED AMMONIA-N (mg/L) AT SURFACE,
MID-DEPTH AND BOTTOM 08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	16	6.75	6.62	1.72	3.64	9.39	0	0	0
1431	12	3.19	2.69	1.45	1.54	5.36	0	0	0
1432	10	0.01	0.01	0.01	.004	0.02	0	0	0
1433	10	3.05	0.41	3.75	.002	7.63	0	0	0
1434	10	0.03	0.01	0.04	.004	0.10	0	0	0
1536	3	0.03	0.03	0.01	.02	0.04	0	0	0
2029	2	0.15	0.15	0.21	.00	0.30	1	0	0
Mid-depth (3 m)									
1419	8	2.49	2.44	2.02	0.00	4.98	1	0	0
1431	6	1.12	0.84	1.12	0.13	3.12	0	0	0
1432	5	0.03	0.01	0.05	0.006	0.13	0	0	0
1433	5	0.51	0.47	0.58	0.00	1.40	1	0	0
1434	5	0.01	0.01	0.01	0.006	0.03	0	0	0
Bottom or depth of turbidity max. (4-20 m)									
1419	16	1.76	1.58	1.15	0.31	3.53	0	0	0
1431	12	0.12	0.08	0.10	0.03	0.32	0	0	0
1432	9	0.01	0.01	0.01	0.00	0.02	1	0	0
1433	10	0.03	0.01	0.04	0.004	0.11	0	0	0
1434	10	0.02	0.01	0.01	0.004	0.03	0	0	0
1536	1	0.01	0.01	-	0.01	0.01	0	0	0
2029	2	0.01	0.01	0.01	0.00	0.01	1	0	0

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)
[3] Number of samples compared to PWQO (temperature and pH required)

FIELD AMMONIA-N (mg/L) AT SURFACE, MID-DEPTH AND BOTTOM, 04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	18	5.17	4.75	2.47	0.92	9.6	0	14	14
1431	12	2.27	2.83	1.30	0.38	3.5	0	7	12
1432	12	1.74	1.26	1.94	0.01	5.0	0	6	12
1433	12	2.46	3.03	1.93	0.06	5.40	0	8	12
1434	12	3.12	3.50	1.79	0.32	5.20	0	10	12
1536	3	0.03	0.02	0.03	0.004	0.06	0	0	3
2029	2	0.006	0.006	0.003	0.004	0.008	0	0	2
Mid-depth (3 m)									
1419	9	1.96	1.60	1.31	0.70	4.80	0	0	0
1431	6	1.79	2.04	1.05	0.40	2.92	0	0	0
1432	6	0.81	0.49	0.92	0.014	2.06	0	0	0
1433	6	1.41	1.08	1.41	0.07	3.70	0	0	0
1434	6	1.22	0.85	1.08	0.26	2.80	0	0	0
Bottom or depth of turbidity max. (4-20 m)									
1419	18	0.91	0.48	1.53	0.20	6.90	0	6	18
1431	12	0.53	0.31	0.59	0.10	1.78	0	2	12
1432	12	0.19	0.08	0.21	0.008	0.52	0	0	12
1433	12	0.23	0.11	0.19	0.08	0.54	0	0	12
1434	12	0.26	0.19	0.15	0.10	0.48	0	0	12
1536	3	0.02	0.01	0.01	0.008	0.03	0	0	3
2029	2	0.007	0.007	0.001	0.006	0.008	0	0	2

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)
[3] Number of samples compared to PWQO (temperature and pH required)

LAB-MEASURED TOTAL AMMONIA (mg/L) AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	14	6.79	6.99	0.96	4.75	7.88	0	14	14
1431	12	2.09	1.36	2.08	0.04	5.48	0	7	10
1432	12	0.40	0.05	0.70	0.02	1.89	0	2	9
1433	12	3.61	3.22	3.68	0.02	8.11	0	6	7
1434	10	1.87	1.89	1.64	0.20	4.54	0	6	10
1536	4	0.043	0.050	0.020	0.014	0.058	0	0	4
2029	4	0.01	0.01	0.01	0.002	0.02	0	0	4
Bottom or depth of turbidity max (4-20 m)									
1419	14	4.16	5.02	2.21	0.06	6.47	0	12	14
1431	12	0.29	0.05	0.41	0.002	1.02	0	4	10
1432	12	0.13	0.016	0.18	0.002	0.46	0	0	9
1433	12	0.69	0.02	1.99	0.002	7.00	0	1	8
1434	10	0.27	0.01	0.36	0.0	0.80	0	4	8
1536	4	0.007	0.002	0.009	0.002	0.02	0	0	4
2029	4	0.02	0.01	0.02	0.002	0.04	0	0	4

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)
[3] Number of samples compared to PWQO (temperature and pH required)

LAB NH_3-N (mg/L) AT SURFACE AND BOTTOM,
08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	16	6.17	6.13	1.44	3.50	8.45	0	0	0
1431	12	2.86	2.03	1.71	0.05	5.5	0	0	0
1432	10	0.14	0.15	0.07	0.05	0.20	0	0	0
1433	10	2.80	0.20	3.48	0.05	7.35	0	0	0
1434	10	0.15	0.15	0.06	0.05	0.20	0	0	0
1536	3	0.10	0.10	0.05	0.05	0.15	0	0	0
2029	2	0.15	0.15	0.07	0.10	0.20	0	0	0
Bottom or depth of turbidity max. (4-20 m)									
1419	16	1.42	1.15	1.11	0.05	3.15	0	0	0
1431	12	0.13	0.13	0.10	0.05	0.40	0	0	0
1432	9	0.13	0.15	0.05	0.05	0.20	0	0	0
1433	10	0.14	0.15	0.06	0.05	0.20	0	0	0
1434	10	0.13	0.15	0.05	0.05	0.20	0	0	0
1536	1	0.05	0.05	-	0.05	0.05	0	0	0
2029	2	0.08	0.08	0.04	0.05	0.10	0	0	0

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)
[3] Number of samples compared to PWQO (temperature and pH required)

LAB NH_3-N (mg/L) AT SURFACE AND BOTTOM,
04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	18	4.55	3.90	2.37	0.80	9.30	0	14	14
1431	12	1.88	2.40	1.34	0.10	3.10	0	7	12
1432	12	1.44	0.93	1.61	0.05	4.10	0	6	12
1433	12	2.13	2.63	1.66	0.05	4.45	0	8	12
1434	12	2.75	3.23	1.63	0.20	4.90	0	10	12
1536	3	0.05	0.05	0.00	0.05	0.05	0	0	3
2029	2	0.10	0.10	0.07	0.05	0.15	0	0	2
Bottom or depth of turbidity max. (4-20 m)									
1419	18	0.59	0.28	1.45	0.05	6.35	0	1	18
1431	12	0.48	0.33	0.51	0.05	1.50	0	0	12
1432	12	0.21	0.10	0.19	0.05	0.50	0	0	12
1433	12	0.15	0.05	0.15	0.05	0.40	0	0	12
1434	12	0.13	0.05	0.12	0.05	0.30	0	0	12
1536	3	0.07	0.05	0.03	0.05	0.10	0	0	3
2029	2	0.18	0.18	0.04	0.15	0.20	0	0	2

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)
[3] Number of samples compared to PWQO (temperature and pH required)

TOTAL PHOSPHORUS (mg/L) AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface (0-1 m)								
1419	14	0.296	0.123	0.249	0.097	0.800	0	14
1431	10	0.118	0.031	0.180	0.014	0.465	0	8
1432	10	0.014	0.010	0.012	0.004	0.035	0	2
1433	10	0.263	0.119	0.416	0.009	1.110	0	6
1434	10	0.102	0.055	0.114	0.009	0.315	0	6
1536	4	0.009	0.009	0.003	0.005	0.013	0	0
2029	4	0.008	0.010	0.003	0.004	0.010	0	0
Bottom or depth of turbidity max. (4-20 m)								
1419	14	0.154	0.109	0.111	0.011	0.370	0	12
1431	10	0.028	0.022	0.018	0.008	0.051	0	5
1432	10	0.015	0.008	0.012	0.005	0.037	0	3
1433	10	0.013	0.009	0.008	0.007	0.029	0	2
1434	10	0.028	0.013	0.027	0.001	0.068	0	4
1536	4	0.004	0.004	0.002	0.002	0.006	0	0
2029	4	0.008	0.010	0.003	0.003	0.010	0	0

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO).

TOTAL PHOSPHORUS (mg/L) AT SURFACE AND BOTTOM, 08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface (0-1 m)								
1419	16	0.116	0.090	0.074	0.006	0.300	0	16
1431	12	0.055	0.060	0.012	0.040	0.080	0	12
1432	10	0.028	0.020	0.010	0.020	0.040	0	4
1433	10	0.074	0.090	0.050	0.020	0.140	0	6
1434	10	0.024	0.020	0.008	0.020	0.040	0	2
1536	3	0.020	0.020	0.000	0.020	0.020	0	0
2029	2	0.020	0.020	0.000	0.020	0.020	0	0
Bottom or depth of turbidity max. (4-20 m)								
1419	16	0.069	0.040	0.061	0.020	0.260	0	14
1431	12	0.065	0.030	0.060	0.020	0.160	0	6
1432	9	0.036	0.040	0.017	0.020	0.060	0	5
1433	10	0.028	0.020	0.010	0.020	0.040	0	4
1434	10	0.034	0.030	0.016	0.020	0.060	0	5
1536	1	0.020	0.020	-	0.020	0.020	0	0
2029	2	0.030	0.030	0.014	0.020	0.040	0	1

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)

TOTAL PHOSPHORUS (mg/L) AT SURFACE AND BOTTOM, 04-07 NOVEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface (0-1 m)								
1419	18	0.078	0.070	0.042	0.020	0.180	0	16
1431	12	0.060	0.060	0.021	0.020	0.080	0	11
1432	12	0.042	0.030	0.028	0.020	0.100	0	6
1433	12	0.038	0.040	0.016	0.020	0.060	0	8
1434	12	0.048	0.050	0.026	0.020	0.100	0	8
1536	3	0.020	0.020	0.000	0.020	0.020	0	0
2029	2	0.020	0.020	0.000	0.020	0.020	0	0
Bottom or depth of turbidity max. (4-20 m)								
1419	18	0.046	0.040	0.028	0.020	0.100	0	10
1431	12	0.052	0.040	0.030	0.020	0.100	0	9
1432	12	0.027	0.020	0.010	0.020	0.040	0	4
1433	12	0.027	0.020	0.010	0.020	0.040	0	4
1434	12	0.038	0.030	0.023	0.020	0.080	0	6
1536	3	0.020	0.020	0.000	0.020	0.020	0	0
2029	2	0.020	0.020	0.000	0.020	0.020	0	0

[1] Number of samples below the detection limit
[2] Number of samples above the Provincial Water Quality Objective (PWQO)

TURBIDITY (FTU) AT SURFACE AND BOTTOM, 12-14 AUGUST 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	14	5.94	2.85	5.25	2.10	16.60
1431	7	2.61	1.55	3.08	0.56	9.50
1432	7	0.95	0.85	0.30	0.61	1.45
1433	8	6.20	2.85	7.69	0.52	18.60
1434	5	2.04	2.50	0.72	1.12	2.60
1536	4	1.66	1.76	0.30	1.22	1.89
2029	4	1.23	0.92	0.92	0.48	2.60
Bottom or depth of turbidity max. (4-20 m)						
1419	14	4.16	3.35	2.57	0.46	8.50
1431	8	1.30	1.19	0.82	0.30	1.37
1432	8	1.01	0.92	0.36	0.51	1.66
1433	8	1.05	1.10	0.19	0.71	1.28
1434	6	1.37	1.29	0.43	0.84	2.10
1536	2	1.38	1.38	0.53	1.00	1.75
2029	4	0.78	0.85	0.28	0.43	1.01

TURBIDITY (FTU) AT SURFACE AND BOTTOM,
08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	16	2.5	2.4	1.1	1.4	5.6
1431	12	1.5	1.5	0.4	0.8	2.1
1432	10	1.1	1.1	0.3	0.6	1.5
1433	10	1.9	1.7	1.0	0.9	3.4
1434	10	1.1	1.0	0.2	0.9	1.6
1536	3	1.9	1.8	0.3	1.7	2.2
2029	2	1.2	1.2	0.3	1.0	1.4
Bottom or depth of turbidity max. (4-20 m)						
1419	16	1.8	1.8	0.4	0.9	2.3
1431	12	2.5	1.4	2.7	0.8	8.5
1432	9	1.2	1.1	0.5	0.7	2.0
1433	10	1.1	1.2	0.3	0.7	1.4
1434	10	1.3	1.2	0.6	0.6	2.8
1536	1	2.2	2.2	-	2.2	2.2
2029	2	0.9	0.9	0.1	0.8	1.0

TURBIDITY (FTU) AT SURFACE AND BOTTOM,
04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	18	9.5	8.3	7.0	1.2	21.0
1431	12	9.8	11.4	5.7	1.9	15.7
1432	12	7.1	7.5	5.1	1.1	15.6
1433	12	7.7	9.7	5.2	1.2	13.8
1434	12	5.8	2.5	5.6	1.4	18.3
1536	3	1.5	1.7	0.6	0.8	1.8
2029	2	2.3	2.3	0.0	2.3	2.3
Bottom or depth of turbidity max. (4-20 m)						
1419	18	17.2	16.3	14.9	1.4	45.0
1431	12	20.6	15.6	19.1	1.2	55.0
1432	12	13.9	9.3	14.4	1.1	35.0
1433	12	14.7	11.5	13.5	1.1	35.0
1434	12	13.4	9.1	11.7	1.3	34.0
1536	3	1.5	1.4	0.8	0.8	2.4
2029	2	3.2	3.2	0.6	2.8	3.6

CHLOROPHYLL _a_ (µg/L) AT SURFACE AND BOTTOM, 08-10 SEPTEMBER 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	16	1.5	1.4	0.4	0.9	2.1
1431	12	1.5	1.4	0.5	1.0	2.5
1432	10	1.4	1.2	0.5	0.8	2.3
1433	10	1.2	1.1	0.4	0.7	2.0
1434	10	1.4	1.3	0.7	0.7	2.5
1536	3	3.8	4.2	1.1	2.5	4.6
2029	2	1.2	1.2	0.1	1.1	1.3
Bottom or depth of turbidity max. (4-20 m)						
1419	16	1.5	1.5	0.6	0.8	2.5
1431	12	2.4	1.9	1.6	1.0	5.7
1432	9	1.2	1.1	0.4	0.8	2.2
1433	10	1.2	1.1	0.5	0.7	2.1
1434	10	1.4	1.2	0.6	0.8	2.5
1536	1	2.6	2.6	-	2.6	2.6
2029	2	1.6	1.6	1.0	0.9	2.3

CHLOROPHYLL _a_ AT SURFACE AND BOTTOM, 04-07 NOVEMBER, 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	13	2.9	2.8	0.7	2.0	4.2
1431	8	3.9	3.5	1.0	3.2	5.7
1432	10	3.1	3.6	1.4	1.3	5.1
1433	8	2.5	2.2	0.6	2.0	3.4
1434	9	2.8	2.6	0.4	2.4	3.5
1536	2	2.7	2.7	0.5	2.3	3.0
2029	-	-	-	-	-	-
Bottom or depth of turbidity max. (4-20 m)						
1419	15	3.0	2.7	1.3	1.6	5.5
1431	10	3.9	4.1	1.2	1.8	5.5
1432	8	2.7	3.0	0.9	1.3	3.9
1433	3	2.8	3.0	1.3	1.3	4.9
1434	10	2.7	2.5	1.1	1.5	4.6
1536	3	2.2	2.4	0.7	1.4	2.8
2029	1	2.8	2.8	-	2.8	2.8

HEAVY METALS
DURING TOXICITY TESTS
1986

COPPER (µg/L) AT SURFACE AND BOTTOM IN 1986

STN	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
12-14 August								
Surface (0 to 1 m water depth)								
1419	6.8	3.0	7.6	1.0	27.0	22	0	6
1536	1.1	1.0	.6	<1.0	2.0	4	1	0
2029	<1.0	<1.0	.3	<1.0	1.0	5	3	0
Bottom or depth of turbidity maximum								
1419	5.7	4.0	5.8	1.0	19.0	9	0	2
1536	1.0	1.0	.0	1.0	1.0	2	0	0
2029	1.0	1.0	.0	1.0	1.0	3	0	0
08-10 September								
Surface (0 to 1 m water depth)								
1419	3.5	3.0	2.1	2.0	10.0	18	0	2
1536	1.5	1.5	.7	1.0	2.0	2	0	0
2029	1.0	1.0	.0	1.0	1.0	2	0	0
Bottom or depth of turbidity maximum								
1419	2.3	2.0	.9	1.0	4.0	14	0	0
1536	<1.0	1.0	.3	<1.0	1.0	2	1	0
2029	1.0	1.0	.0	1.0	1.0	2	0	0
04-07 November								
Surface (0 to 1 m water depth)								
1419	3.9	3.5	1.6	2.0	7.0	18	0	3
1536	<1.0	1.0	.3	<1.0	1.0	3	1	0
2029	1.0	1.0	.0	1.0	1.0	2	0	0
Bottom or depth of turbidity maximum								
1419	2.9	2.5	1.8	1.0	6.0	18	0	4
1536	1.0	1.0	.0	1.0	1.0	3	0	0
2029	1.0	1.0	.0	1.0	1.0	2	0	0

IRON (µg/L) AT SURFACE AND BOTTOM IN 1986

VARIABLE	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
12-14 August								
Surface (0 to 1 m water depth)								
1419	313.	165.	326.	19.	1200.	22	0	6
1536	35.	38.	20.	9.	60.	6	0	0
2029	14.	6.	21.	<1.	50.	5	1	0
Bottom or depth of turbidity maximum								
1419	208.	150.	168.	32.	510.	9	0	2
1536	34.	34.	7.	29.	39.	2	0	0
2029	11.	7.	9.	5.	21.	3	0	0
08-10 September								
Surface (0 to 1 m water depth)								
1419	143.	120.	91.	73.	400.	18	0	2
1536	58.	58.	30.	37.	80.	2	0	0
2029	14.	14.	8.	8.	20.	2	0	0
Bottom or depth of turbidity maximum								
1419	80.	50.	52.	40.	170.	14	0	0
1536	38.	38.	12.	30.	47.	2	0	0
2029	14.	14.	6.	10.	19.	2	0	0
04-07 November								
Surface (0 to 1 m water depth)								
1419	434.	395.	274.	110.	900.	18	0	12
1536	29.	21.	20.	14.	52.	3	0	0
2029	30.	30.	23.	14.	46.	2	0	0
Bottom or depth of turbidity maximum								
1419	581.	490.	489.	39.	1500.	18	0	11
1536	25.	31.	11.	13.	32.	3	0	0
2029	45.	45.	21.	31.	60.	2	0	0

MERCURY (µg/L) AT SURFACE AND BOTTOM IN 1986

VARIABLE	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
12-14 August								
Surface (0 to 1 m water depth)								
1419	.02	.01	.02	<.01	.05	21	2	0
1536	.04	.03	.05	.01	.15	6	0	0
2029	<.01	<.01	.00	<.01	<.01	3	3	0
Bottom or depth of turbidity maximum								
1419	.01	.01	.01	<.01	.02	7	1	0
1536	<.01	<.01	.00	<.01	<.01	2	2	0
2029	<.01	<.01	.	<.01	<.01	1	1	0
08-10 September								
Surface (0 to 1 m water depth)								
1419	<.01	.01	.01	<.01	.03	18	8	0
1536	<.01	<.01	.00	<.01	<.01	2	2	0
2029	<.01	<.01	.00	<.01	<.01	2	2	0
Bottom or depth of turbidity maximum								
1419	<.01	<.01	.01	<.01	.03	14	12	0
1536	<.01	<.01	.00	<.01	<.01	2	2	0
2029	<.01	<.01	.00	<.01	<.01	2	2	0
04-07 November								
Surface (0 to 1 m water depth)								
1419	.02	.02	.01	<.01	.03	18	1	0
1536	<.01	<.01	.00	<.01	<.01	3	3	0
2029	<.01	<.01	.00	<.01	<.01	2	2	0
Bottom or depth of turbidity maximum								
1419	<.01	.01	.00	<.01	.02	18	8	0
1536	<.01	<.01	.00	<.01	<.01	3	3	0
2029	<.01	<.01	.00	<.01	<.01	2	2	0

ZINC (µg/L) AT SURFACE AND BOTTOM IN 1986

STN	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
12-14 August								
Surface (0 to 1 m water depth)								
1419	17.3	11.0	15.6	2.0	58.0	22	0	3
1536	1.7	<1.0	2.2	<1.0	6.0	6	4	0
2029	1.7	1.0	1.4	<1.0	4.0	5	1	0
Bottom or depth of turbidity maximum								
1419	16.0	12.0	15.6	3.0	54.0	9	0	1
1536	<3.0	<3.0	3.2	<1.0	5.0	2	1	0
2029	2.7	3.0	.6	2.0	3.0	3	0	0
08-10 September								
Surface (0 to 1 m water depth)								
1419	12.1	6.0	15.3	3.0	70.0	18	0	1
1536	6.5	6.5	6.4	2.0	11.0	2	0	0
2029	<1.5	<1.5	1.1	<1.0	2.0	2	1	0
Bottom or depth of turbidity maximum								
1419	2.6	2.0	2.1	<1.0	8.0	14	1	0
1536	1.0	1.0	.0	1.0	1.0	2	0	0
2029	2.5	2.5	2.1	1.0	4.0	2	0	0
04-07 November								
Surface (0 to 1 m water depth)								
1419	8.4	8.0	3.4	3.0	17.0	18	0	0
1536	1.3	1.0	.6	1.0	2.0	3	0	0
2029	1.0	1.0	.0	1.0	1.0	2	0	0
Bottom or depth of turbidity maximum								
1419	6.8	5.0	4.3	2.0	15.0	18	0	0
1536	2.3	3.0	1.2	1.0	3.0	3	0	0
2029	2.0	2.0	1.4	1.0	3.0	2	0	0

CONVENTIONALS AND HEAVY METALS
DURING TOXICITY TESTS
1987

STATION 1419 WATER QUALITY AT 0.5 and
6 M DEPTHS, 15-19 JUNE 1987

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	PWQO[3]	N[4]
0.5 m									
Time (hours)	7	11.0	9.9	1.9	9.3	13.8			
Temp. (°C)	6	12.9	12.8	0.4	12.4	13.5			
Chlorine (µg/L)	6	513	510	175	320	700	0	6	6
Ammonia	6	5.46	5.72	2.97	0.56	8.30	0	3	4
Lab Ammonia	0	-	-	-	-	-	-	-	-
pH (units)	5	7.2	7.3	0.4	6.6	7.4	-	-	-
Phosphorus	7	0.14	0.11	0.11	0.08	0.39	0	7	7
Cadmium (µg/L)	7	1.45	0.15	2.91	0.15	13.0	5	2	7
Copper	7	0.005	0.004	0.004	0.001	0.013	0	1	7
Iron	7	0.284	0.300	0.093	0.170	0.410	0	3	7
Mercury (µg/L)	7	0.015	0.010	0.009	0.005	0.030	1	0	7
Zinc	7	0.006	0.007	0.004	0.001	0.011	2	0	7
Turbidity (ftu)	6	3.31	3.20	1.22	1.76	5.40			
6.0 m									
Time (hours)	6	10.8	10.1	1.7	9.5	14.1			
Temp (°C)	5	8.5	8.4	1.2	6.8	10.1			
Chlorine (µg/L)	4	0	0	0	0	0	4	0	4
Ammonia	5	0.29	0.29	0.20	0.04	0.59	0	0	2
Lab Ammonia	0	-	-	-	-	-	-	-	-
pH (units)	2	7.8	7.8	0.2	7.7	7.9	-	-	-
Phosphorus	5	0.04	0.04	0.02	0.02	0.07	0	4	5
Cadmium (µg/L)	5	2.36	0.15	4.43	0.15	9.00	4	1	5
Copper	5	0.003	0.001	0.004	0.001	0.010	1	1	5
Iron	5	0.182	0.150	0.110	0.082	0.350	0	3	5
Mercury (µg/L)	5	0.005	0.005	0	0.005	0.005	1	0	5
Zinc	5	0.004	0.002	0.006	0.001	0.014	1	0	5
Turbidity (ftu)	5	2.60	2.20	0.75	2.00	3.60			

[1] Parameter units are mg/L unless otherwise indicated.
[2] Number of samples below detection limit.
[3] Number of samples above Provincial Water Quality Objectives (PWQO).
[4] Number of samples compared to PWQO.

STATION 1419 WATER QUALITY AT 0.5 and
6 M DEPTHS, 16 JUNE-08 JULY 1987

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	PWQO[3]	N[4]
0.5 m									
Time (hours)	6	11.2	10.4	2.0	9.3	13.8			
Temp. (°C)	5	13.0	12.9	0.4	12.4	13.5			
Chlorine (µg/L)	5	496	420	190	320	700	0	5	5
Ammonia	5	4.91	4.50	2.96	0.56	8.30	2	0	3
Lab Ammonia	0	-	-	-	-	-	-	-	-
pH (units)	4	-	-	-	-	-	-	-	-
Phosphorus	6	0.10	0.11	0.02	0.08	0.13	6	0	6
Cadmium	6						2	4	6
Copper	6	0.005	0.004	0.004	0.001	0.013	1	0	6
Iron	6	0.277	0.265	0.100	0.170	0.410	2	0	6
Mercury (µg/L)	6	0.013	0.010	0.006	0.005	0.020	0	1	6
Zinc	6	0.006	0.006	0.004	0.001	0.011	0	2	6
Turbidity (ftu)	5	3.23	3.20	1.35	1.76	5.40			
6.0 m									
Time (hours)	5	11.0	10.1	1.8	9.5	14.1			
Temp. (°C)	4	8.9	8.7	0.8	8.3	10.1			
Chlorine (µg/L)	4	0	0	0	0	0	4	0	4
Ammonia	4	0.36	0.31	0.16	0.23	0.59	0	0	2
Lab Ammonia	0	-	-	-	-	-	-	-	-
pH (units)	2	-	-	-	-	-	-	-	-
Phosphorus	5	0.04	0.04	0.02	0.02	0.07	4	0	5
Cadmium	4						0	4	4
Copper	4	0.001	0.001	0	0.001	0.001	0	1	4
Iron	4	0.191	0.165	0.125	0.082	0.350	1	0	4
Mercury (µg/L)	5	0.005	0.005	0	0.005	0.005	0	5	5
Zinc	4	0.002	0.002	0.001	0.001	0.002	0	1	4
Turbidity (ftu)	5	2.60	2.20	0.75	2.00	3.60			

[1] Parameter units are mg/L unless otherwise indicated.
[2] Number of samples below detection limit.
[3] Number of samples above Provincial Water Quality Objectives (PWQO).
[4] Number of samples compared to PWQO.

APPENDIX 2

Water Quality Statistical Summaries for Each Survey Year

ANNUAL MEAN

CONVENTIONALS

1986

MAIN STP (STATION 22) FINAL EFFLUENT QUALITY – ANNUAL MEAN, 1986

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	IWDG[3]
Time (hours)	16	12.7	13.0	1.3	10.0	14.5		
Lab Ammonia	14	20.6	21.5	5.2	6.7	28.5		
Phosphorus	15	0.79	0.49	0.77	0.22	2.92	0	3
Nitrite/Nitrate	11	0.90	0.62	1.02	0.05	3.31		
TKN	15	23.9	24.3	5.44	10.06	32.3		
Suspended Solids	15	18.2	11.6	17.5	4.3	54.9	0	5
Fecal Coliforms (log #/100 mL)	11	3.81	3.82	0.92	2.80	5.15		

[1] Parameter units are mg/L unless otherwise indicated.
[2] Number of samples below detection limit.
[3] Number of samples above Industrial Waste Discharge Guidelines (IWDG).

MAIN STP (STATION 03-22) FINAL EFFLUENT QUALITY (μg/L), ANNUAL MEAN, 1986

PAR.	MEAN	MEDIAN	STD. DEV.	MIN	MAX	N
Cd	0.84	0.56	0.65	0.28	2.22	15
Cr	25.0	17.	16.	8.	60.3	15
Cu	27.	18.	26.	5.	92.	15
Fe	876.	676.	581.	311.	1998.	15
Hg	0.08	0.07	0.06	0.02	0.22	15
Mn	57.	54.	20.	30.	126.5	15
Ni	33.	27.	24.	13.	116.	15
Zn	56.	52.	44.	12.	145.	15

TIME OF SAMPLING (HOURS) AT SURFACE, MID-DEPTH, AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	10	13.9	14.1	1.1	12.3	15.6
1431	10	13.5	13.4	1.4	11.9	15.9
1432	10	13.7	13.2	1.4	12.2	16.5
1433	10	14.1	16.7	1.5	12.6	17.0
1434	10	14.9	15.0	1.4	13.1	17.5
1536	8	11.3	10.6	2.6	8.8	15.3
2029	7	10.7	10.0	2.5	8.5	16.0
Mid-depth (3 m)						
1419	6	13.3	12.8	1.1	12.3	15.1
1431	6	13.4	13.0	1.4	11.9	15.2
1432	6	13.3	12.8	1.2	12.4	15.6
1433	6	13.7	13.3	1.1	12.7	15.9
1434	6	14.2	13.6	1.3	13.1	16.3
Bottom or depth of turbidity max. (4-20 m)						
1419	10	13.9	14.1	1.0	12.3	15.6
1431	10	13.5	13.4	1.4	11.9	15.9
1432	10	13.7	13.2	1.4	12.2	16.5
1433	10	14.1	13.7	1.5	12.6	17.0
1434	10	14.9	15.0	1.4	13.1	17.5
1536	7	10.8	9.9	2.2	8.8	15.3
2029	7	10.7	10.0	2.5	8.5	16.0

TEMPERATURE (°C) - AT SURFACE, MID-DEPTH, AND BOTTOM-ANNUAL MEAN 1986.

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	9	13.0	12.2	1.9	11.2	16.3
1431	9	11.5	10.3	2.6	9.0	17.1
1432	9	10.1	9.6	3.1	5.8	16.4
1433	9	11.6	11.4	3.3	6.0	17.1
1434	9	10.6	10.2	3.1	6.2	16.8
1536	8	12.8	13.6	3.1	9.1	16.7
2029	6	10.3	9.0	4.4	6.6	19.0
Mid-depth (3 m)						
1419	6	10.2	9.7	2.1	8.6	14.3
1431	6	9.4	9.2	2.4	7.0	13.4
1432	6	8.6	8.6	2.4	5.8	12.6
1433	5	8.3	8.7	1.6	5.8	9.8
1434	6	8.8	9.0	2.2	5.9	12.1
Bottom or depth of turbidity max. (4-20 m)						
1419	9	9.8	9.0	2.2	7.7	14.1
1431	9	8.6	8.6	2.3	6.0	12.6
1432	9	8.5	8.5	2.5	5.6	12.6
1433	9	8.4	8.6	2.3	5.8	12.3
1434	8	8.6	8.7	2.6	5.8	12.6
1536	5	9.2	9.2	1.3	7.3	11.0
2029	6	7.3	7.2	1.4	5.6	9.0

CONDUCTIVITY (UMHO/CM) AT SURFACE, MID-DEPTH, AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	9	515	508	33	459	585
1431	9	404	416	50	327	484
1432	9	329	313	29	308	392
1433	9	424	456	91	305	564
1434	9	377	332	85	311	516
1536	8	313	312	6	305	323
2029	6	310	310	7	299	321
Mid-depth (3 m)						
1419	6	388	382	41	338	459
1431	6	348	344	26	316	384
1432	6	322	314	23	309	368
1433	5	339	338	29	313	386
1434	6	331	313	32	310	386
Bottom or depth of turbidity max. (4-20 m)						
1419	9	356	346	35	310	405
1431	9	320	318	13	302	346
1432	9	313	312	4	306	320
1433	9	314	313	5	306	324
1434	8	315	314	8	304	329
1536	5	310	309	3	307	314
2029	6	310	309	3	305	313

FIELD-MEASURED CHLORINE RESIDUAL (µg/l) AT SURFACE, MID-DEPTH, AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
Surface (0-1 m)								
1419	7	751.8	533.3	890.0	20.5	2722.0	0	7
1431	6	244.5	111.5	301.5	0.0	778.0	1	5
1432	7	0.9	0.0	1.6	0.0	4.0	5	2
1433	7	140.0	50.0	184.8	0.0	500.0	2	5
1434	7	28.7	13.0	49.9	0.0	138.0	3	4
1536	5	0.0	0.0	0.0	0.0	0.0	5	0
2029	6	4.0	0.0	8.9	0.0	20.0	4	1
Mid-depth (3 m)								
1419	3	163.0	200.0	139.2	9.0	280.0	0	6
1431	3	80.0	67.0	94.9	2.0	189.0	0	3
1432	3	0.0	0.0	0.0	0.0	0.0	2	0
1433	3	18.3	0.0	31.8	0.0	55.0	2	1
1434	2	0.0	0.0	0.0	0.0	0.0	2	0
Bottom or depth of turbidity max. (4-20 m)								
1419	6	213.5	155.0	220.6	7.0	633.3	0	6
1431	6	6.7	0.0	14.9	0.0	37.0	4	2
1432	7	8.1	0.0	21.5	0.0	57.0	6	1
1433	7	1.4	0.0	3.8	0.0	10.0	6	1
1434	7	3.1	0.0	8.1	0.0	21.5	6	1
1536	4	0.0	0.0	0.0	0.0	0.0	4	0
2029	5	0.0	0.0	0.0	0.0	0.0	5	0

[1] Number of samples below detection limit (assumed to be zero).
[2] Number of samples above Provincial Water Quality Objectvies (PWQO).

FIELD MEASURED AMMONIA-N (mg/l) AT SURFACE, MID-DEPTH AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	9	6.48	6.90	1.42	4.03	8.05	0	6	6
1431	10	2.64	2.61	1.76	0.00	5.11	1	5	5
1432	10	0.67	0.03	1.2	0.00	3.75	1	3	6
1433	10	3.05	1.68	3.43	0.00	8.55	1	4	6
1434	10	1.48	0.58	1.8	0.0	4.28	1	5	6
1536	8	0.02	0.02	0.02	0.004	0.6	0	0	6
2029	7	0.05	0.01	0.11	0.0	0.30	2	0	4
Mid-depth (3 m)									
1419	6	2.10	1.87	1.43	0.25	4.05	0	0	0
1431	6	1.46	1.58	0.99	0.20	2.43	0	0	0
1432	6	0.42	0.04	0.76	0.009	1.93	0	0	0
1433	6	0.96	0.75	1.12	0.004	3.5	0	0	0
1434	6	0.62	0.16	0.98	0.007	2.50	0	0	0
Bottom or depth of turbidity max. (4-20 m)									
1419	9	2.03	1.55	1.92	0.05	6.00	0	4	6
1431	10	0.31	0.15	0.41	0.0	1.13	1	2	6
1432	10	0.13	0.03	0.18	0.0	0.46	1	0	6
1433	10	0.20	0.10	0.25	0.0	0.77	1	0	6
1434	10	0.26	0.09	0.35	0.0	1.00	1	1	5
1536	7	0.02	0.02	0.01	0.008	0.04	0	0	4
2029	7	0.08	0.05	0.07	0.0	0.20	2	0	4

[1] Number of samples below detection limit (assumed to be zero).
[2] Number of samples above Provincial Water Quality Objectives (PWQO).
[3] Number of samples compared to PWQO (temperature and pH required).

LAB MEASURED AMMONIA-N (mg/L) AT SURFACE AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	NP[3]
Surface (0-1 m)									
1419	10	5.81	6.56	1.33	3.50	7.05	0	6	6
1431	10	2.26	2.33	1.63	0.04	4.88	0	5	6
1432	10	0.59	0.16	0.94	0.02	2.96	0	3	6
1433	10	2.74	1.44	3.11	0.02	7.55	0	4	6
1434	9	1.49	0.74	1.62	0.05	3.98	0	5	6
1536	8	0.06	0.05	0.03	0.01	0.12	0	0	6
2029	7	0.08	0.05	0.08	0.002	0.20	0	0	4
Bottom or depth of turbidity max. (4-20 m)									
1419	10	1.58	1.27	1.86	0.33	5.56	0	3	6
1431	10	0.27	0.11	0.35	0.003	0.99	0	1	6
1432	10	0.14	0.08	0.16	0.002	0.46	0	0	6
1433	10	0.29	0.09	0.53	0.002	1.75	0	1	6
1434	9	0.16	0.06	0.21	0.002	0.67	0	1	5
1536	7	0.08	0.05	0.08	0.002	0.20	0	0	4
2029	7	0.08	0.05	0.07	0.002	0.20	0	0	4

[1] Number of samples below detection limit.
[2] Number of samples above Provincial Water Quality Objectives (PWQO).
[3] Number of samples compared to PWQO (temperature and pH required).

pH AT SURFACE AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	7	7.86	7.85	0.04	7.81	7.90
1431	7	8.06	8.13	0.21	7.62	8.22
1432	7	8.23	8.28	0.09	8.06	8.31
1433	7	8.08	8.05	0.14	7.92	8.28
1434	7	8.10	8.20	0.20	7.84	8.36
1536	6	8.35	8.34	0.05	8.30	8.41
2029	5	8.32	8.28	0.09	8.24	8.47
Bottom or depth of turbidity max. (4-20 m)						
1419	7	8.14	8.21	0.20	7.87	8.42
1431	7	8.20	8.23	0.08	8.06	8.30
1432	7	8.25	8.24	0.04	8.21	8.32
1433	7	8.27	8.27	0.05	8.21	8.36
1434	7	8.21	8.26	0.09	8.03	8.28
1536	5	8.30	8.27	0.06	8.25	8.39
2029	5	8.27	8.28	0.04	8.22	8.31

TOTAL PHOSPHORUS (mg/L) AT SURFACE AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQG[2]
Surface (0-1 m)								
1419	10	0.145	0.107	0.110	0.040	0.413	0	10
1431	9	0.074	0.060	0.066	0.020	0.244	0	8
1432	9	0.027	0.020	0.021	0.005	0.075	0	3
1433	9	0.118	0.045	0.181	0.010	0.588	0	7
1434	9	0.053	0.025	0.053	0.011	0.179	0	6
1536	8	0.016	0.020	0.006	0.007	0.020	0	0
2029	7	0.015	0.020	0.007	0.004	0.020	0	0
Bottom or depth of turbidity max. (4-20 m)								
1419	10	0.073	0.048	0.063	0.014	0.199	0	8
1431	9	0.047	0.030	0.044	0.013	0.145	0	6
1432	9	0.026	0.025	0.015	0.007	0.050	0	5
1433	9	0.002	0.020	0.011	0.008	0.040	0	3
1434	9	0.032	0.030	0.020	0.002	0.059	0	5
1536	7	0.013	0.020	0.009	0.003	0.020	0	0
2029	7	0.017	0.020	0.012	0.003	0.040	0	1

1 Number of samples below detection limit.
2 Number of samples above Provincial Water Quality Guidelines (PWQG).
(Guidelines for control of nuisance algae).

TURBIDITY (FTU) AT SURFACE AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	10	5.5	3.4	5.0	2.0	18.1
1431	9	4.5	1.7	5.1	1.0	14.1
1432	9	3.0	1.2	4.0	0.9	4.2
1433	9	4.7	2.0	4.7	0.6	11.9
1434	9	3.0	1.8	3.8	1.0	12.8
1536	8	1.6	1.8	0.4	0.8	2.2
2029	7	1.6	1.4	0.8	0.6	2.6
Bottom or depth of turbidity max. (4-20 m)						
1419	10	6.8	2.1	10.6	0.7	34.3
1431	9	8.2	1.7	14.4	0.8	44.5
1432	9	5.3	1.3	10.5	0.7	32.8
1433	9	5.6	1.2	10.4	0.8	32.0
1434	9	5.4	1.5	8.9	1.0	27.8
1536	6	1.6	1.6	0.6	0.8	2.4
2029	7	1.5	1.0	1.2	0.6	3.6

CHLOROPHYLL A (μg/L) AT SURFACE AND BOTTOM-ANNUAL MEAN 1986

STN	N	MEAN	MEDIAN	SD	MIN	MAX
Surface (0-1 m)						
1419	9	1.8	1.6	0.7	1.1	3.5
1431	7	2.1	1.4	1.3	1.0	4.3
1432	8	2.1	1.5	1.3	0.9	4.2
1433	7	1.7	1.6	0.6	0.8	2.7
1434	8	1.9	1.7	0.9	0.8	3.3
1536	7	2.7	2.3	1.1	1.3	4.6
2029	4	1.4	1.2	0.5	1.1	2.1
Bottom or depth of turbidity max. (4-20 m)						
1419	8	2.2	1.7	1.2	1.0	4.4
1431	8	2.8	3.0	1.2	1.0	4.2
1432	7	1.8	1.4	0.8	1.0	3.3
1433	8	2.1	1.6	1.4	0.8	4.9
1434	8	2.1	1.8	1.1	0.9	4.4
1536	7	1.9	1.6	0.6	1.3	2.8
2029	5	1.8	2.3	1.0	0.7	2.8

ANNUAL MEAN
HEAVY METALS
1986

MAIN STP (STATION 22) FINAL EFFLUENT QUALITY, ANNUAL MEAN, 1986

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	IWDG[3]
Time (hours)	16	12.7	13.0	1.3	10.0	14.5		
Cadmium (µg/L)	15	0.793	0.561	0.628	0.150	2.34	2	4
Chromium	15	0.025	0.023	0.015	0.012	0.059	0	0
Copper	15	0.027	0.015	0.024	0.006	0.081	0	0
Iron	15	0.844	0.615	0.585	0.323	2.292	0	-
Mercury (µg/L)	15	0.075	0.062	0.053	0.020	0.186	0	0
Manganese	15	0.054	0.053	0.005	0.049	0.068	0	-
Nickel	15	0.027	0.025	0.008	0.015	0.039	0	0
Zinc	15	0.070	0.049	0.050	0.018	0.195	0	0

[1] Parameter units are mg/L unless otherwise indicated.

[2] Number of samples below detection limit.

[3] Number of samples above Industrial Waste Discharge Guidelines (IWDG).

STATION 1419 WATER QUALITY (µg/L) AT SURFACE AND BOTTOM, ANNUAL MEAN, 1986

(a) Surface (0 to 1 m water depth)

PAR.	MEAN	MEDIAN	STD. DEV.	MIN	MAX	N	DL	PWQO
Cd	0.18	0.15	0.05	0.15	0.27	10	0	2
Cr	5.0	5.3	2.3	1.8	9.3	10	0	0
Cu	4.4	3.3	2.4	1.5	8.9	10	0	3
Fe	281.	244.	213.	66.	773.	10	0	4
Hg	0.02	0.02	0.01	<0.01	0.04	9	1	1
Mn	15.	16.	6.	6.8	28.5	10	0	-
Ni	7.	7.	2.	4.3	11.2	10	0	0
Zn	12.	11.	7.	3.8	22.9	10	0	0

(b) Bottom or depth of turbidity maximum (4 to 6 m water depth)

VAR.	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
Cd	0.30	0.15	0.44	0.15	1.46	9	0	1
Cr	3.0	2.2	2.3	0.8	8.2	9	0	0
Cu	3.0	2.5	2.0	1.0	7.7	9	0	1
Fe	272.	89.	345.	46.	1037.	9	0	2
Hg	0.01	0.01	0.00	<0.01	0.02	8	3	0
Mn	9.	4.	9.	2.	25.	9	0	-
Ni	4.	3.	4.	1.	15.	9	0	0
Zn	7.	5.	6.	2.	21.	9	0	0

Note: DL = Number of samples below detection limit.
PWQO = Number of samples above Provincial Water Quality Objective (PWQO).

STATION 1536 WATER QUALITY (µg/L) AT SURFACE AND BOTTOM, ANNUAL MEAN, 1986

(a) Surface (0 to 1 m water depth)

PAR.	MEAN	MEDIAN	STD. DEV.	MIN	MAX	N	DL	PWQO
Cd				<0.3	<0.3	8	8	0
Cr				<1.0	1.0	8	5	0
Cu	1.1	1.0	0.5	<1.0	2.0	8	2	0
Fe	42.	44.	22.	14.	80.	8	0	0
Hg				<0.01	0.06	8	5	0
Mn	2.6	2.0	1.6	1.0	5.0	8	0	-
Ni				<2.0	2.0	8	7	0
Zn	3.2	2.0	3.6	<1.0	11.0	8	2	0

(b) Bottom or depth of turbidity maximum (4 to 20 m water depth)

PAR.	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
Cd				<0.3	<0.3	7	7	0
Cr				<1.0	2.0	7	4	0
Cu	0.9	1.0	0.2	<1.0	1.0	7	1	0
Fe	32.	31.	10.	13.	47.	7	0	0
Hg				<0.01	<0.01	7	7	0
Mn	1.7	2.0	0.8	1.0	3.0	7	0	-
Ni				<2.0	4.0	7	6	0
Zn	2.1	1.0	1.6	<1.0	5.0	7	2	0

Note: DL = Number of samples below detection limit.
PWQO = Number of samples above Provincial Water Quality Objective (PWQO).

STATION 2029 WATER QUALITY (μg/L) AT SURFACE AND BOTTOM, ANNUAL MEAN, 1986

(a) Surface (0 to 1 m water depth)

PAR.	MEAN	MEDIAN	STD. DEV.	MIN	MAX	N	DL	PWQO
Cd				<0.3	<0.3	7	7	0
Cr				<1.0	1.0	7	4	0
Cu	0.9	1.0	0.2	<1.0	1.0	7	2	0
Fe	21.0	14.0	19.3	3.3	50.0	7	0	0
Hg				<0.01	<0.01	6	6	0
Mn	1.3	1.0	0.8	0.8	3.0	7	1	-
Ni				<2.0	2.0	7	6	0
Zn	1.4	1.0	0.8	0.5	2.5	7	2	0

(b) Bottom or depth of turbidity maximum (6 to 15 m water depth)

PAR.	MEAN	MEDIAN	STD DEV	MIN	MAX	N	DL	PWQO
Cd				<0.3	<0.3	6	6	0
Cr				<1.0	1.0	6	5	0
Cu	1.0	1.0	0.0	1.0	1.0	6	0	0
Fe	25.	20.	19.	6.	60.	6	0	0
Hg				<0.01	<0.01	5	5	0
Mn	1.2	1.0	0.4	1.0	2.0	6	0	-
Ni				<2.0	2.0	6	5	0
Zn	2.4	2.7	1.2	1.0	4.0	6	0	0

Note: DL = Number of samples below detection limit.
PWQO = Number of samples above Provincial Water Quality Objective (PWQO).

ANNUAL MEAN
CONVENTIONALS
1987

MAIN STP (STATION 22) FINAL EFFLUENT QUALITY, ANNUAL MEAN, 1987

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	IWDG[3]
Time (hours)	25	10.6	10.7	1.8	8.3	13.7		
Lab Ammonia	25	21.0	20.5	4.9	8.9	31.3		
pH (units)	24	7.4	7.4	0.4	6.6	8.1		
Phosphorus	25	0.83	0.34	1.57	0.12	7.53	0	2
Nitrite/Nitrate	23	0.85	0.25	2.09	0.05	10.2		
TKN	23	30.3	25.6	20.7	17.2	121.3		
Conductivity (umhos/cm)	25	924	938	70	705	1,027		
DOC	23	14.0	14.3	2.6	9.8	18.5		
Suspended Solids	25	27.5	8.7	72.9	3.1	362.5	0	4
Fecal Coliforms (log #/100 mL)	24	3.48	2.94	1.54	1.37	6.17		

[1] Parameter units are mg/L unless otherwise indicated.

[2] Number of samples below detection limit.

[3] Number of samples above Industrial Waste Discharge Guidelines (IWDG).

CONDUCTIVITY (umhos/cm) AT 0.5 AND 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	10	340	337	19	317	380
1419	12	517	516	37	443	580
2877	10	347	326	42	311	419
2909	10	342	329	33	311	401
2891	10	320	315	21	301	378
2886	10	315	315	7.9	302	332
1536	10	316	314	9.7	303	332
2878	10	358	331	62	300	479
2910	9	328	325	16	306	357
2209	14	320	315	15	300	350
2892	14	312	312	9.6	291	327
2029	9	312	312	8.8	299	330
6.0 m						
2036	0	-	-	-	-	-
1419	3	321	320	2.6	319	324
2877	0	-	-	-	-	-
2909	0	-	-	-	-	-
2891	0	-	-	-	-	-
2886	0	-	-	-	-	-
1536	0	-	-	-	-	-
2878	0	-	-	-	-	-
2910	0	-	-	-	-	-
2209	0	-	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

DOC (mg/L) AT 0.5 AND 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	9	2.36	2.30	0.42	1.8	3.0
1419	13	5.64	5.75	0.73	4.6	6.9
2877	9	2.57	2.10	0.90	1.7	4.0
2909	9	2.42	2.20	0.74	1.7	3.5
2891	9	2.10	1.90	0.54	1.8	3.5
2886	9	2.00	2.00	0.17	1.7	2.2
1536	9	2.02	2.00	0.16	1.8	2.3
2878	9	2.73	2.60	0.78	2.0	4.1
2910	8	2.20	2.10	0.29	1.9	2.8
2209	14	2.07	2.00	0.22	1.7	2.6
2892	14	1.96	2.00	0.13	1.7	2.1
2029	8	1.93	1.95	0.15	1.7	2.1
6.0 m						
2036	0	-	-	-	-	-
1419	5	1.99	2.00	0.13	1.85	2.2
2877	0	-	-	-	-	-
2909	0	-	-	-	-	-
2891	0	-	-	-	-	-
2886	0	-	-	-	-	-
1536	0	-	-	-	-	-
2878	0	-	-	-	-	-
2910	0	-	-	-	-	-
2209	0	-	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

SUSPENDED SOLIDS (mg/L) AT 0.5 AND
6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	9	8.86	5.5	10.9	3.0	37.3
1419	13	8.03	6.2	7.22	3.2	30.5
2877	9	2.86	2.3	1.69	1.0	6.0
2909	9	2.61	2.7	1.26	1.5	5.2
2891	9	1.55	1.3	1.72	0.1	5.8
2886	9	1.19	1.1	0.45	0.7	1.9
1536	9	1.17	1.1	0.42	0.6	1.8
2878	9	3.19	2.3	2.83	0.8	10.3
2910	7	1.83	1.4	1.07	0.9	4.0
2209	14	2.23	2.2	1.22	0.8	5.7
2892	14	1.24	1.1	0.89	0.1	3.7
2029	8	5.14	0.8	12.3	0.2	35.6
6.0 m						
2036	0	-	-	-	-	-
1419	5	4.25	3.9	1.38	2.4	6.0
2877	0	-	-	-	-	-
2909	0	-	-	-	-	-
2891	0	-	-	-	-	-
2886	0	-	-	-	-	-
1536	0	-	-	-	-	-
2878	0	-	-	-	-	-
2910	0	-	-	-	-	-
2209	0	-	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

FECAL COLIFORMS (log #/100 mL) AT 0.5 AND
6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	6	2.06	2.26	0.97	0.30	2.96
1419	9	2.66	2.14	1.47	1.60	6.09
2877	6	0.81	0.80	0.48	0.30	1.48
2909	6	0.65	0.54	0.66	0.0	1.48
2891	6	0.34	0.15	0.55	0.0	1.42
2886	6	0.35	0.30	0.23	0.0	0.60
1536	6	0.60	0.45	0.50	0.0	1.20
2878	6	2.05	1.34	1.97	0.0	5.18
2910	5	1.79	1.0	2.12	0.0	5.18
2209	10	0.63	0.30	0.86	0.0	2.52
2892	10	0.20	0.0	0.34	0.0	1.08
2029	6	0.10	0.0	0.25	0.0	0.60
6.0 m						
2036	0	-	-	-	-	-
1419	0	-	-	-	-	-
2877	0	-	-	-	-	-
2909	0	-	-	-	-	-
2891	0	-	-	-	-	-
2886	0	-	-	-	-	-
1536	0	-	-	-	-	-
2878	0	-	-	-	-	-
2910	0	-	-	-	-	-
2209	0	-	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

FIELD-MEASURED FREE CHLORINE (µg/L) AT 0.5 and 6 M DEPTHS, ANNUAL MEAN, JUNE-SEPTEMBER 1987*

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]
0.5 m								
2036	7	6.0	0	15.9	0	42.0	6	1
1419	13	332.2	340.0	263.0	0	700.0	4	9
2877	7	47.7	58.0	49.0	0	106.0	2	5
2909	7	36.0	20.0	46.0	0	120.0	2	5
2891	7	0	0	0	0	0	7	0
2886	6	0	0	0	0	0	6	0
1536	7	0	0	0	0	0	7	0
2878	7	0	0	0	0	0	7	0
2910	5	0	0	0	0	0	5	0
2209	13	2.3	0	8.3	0	30	12	1
2892	12	0.8	0	2.9	0	10	11	1
2029	6	0	0	0	0	0	6	0
6.0 m								
2036	0	-	-	-	-	-	-	-
1419	5	0	0	0	0	0	5	0
2877	0	-	-	-	-	-	-	-
2909	0	-	-	-	-	-	-	-
2891	0	-	-	-	-	-	-	-
2886	1	0	0	0	0	0	1	0
1536	0	-	-	-	-	-	-	-
2878	0	-	-	-	-	-	-	-
2910	0	-	-	-	-	-	-	-
2209	0	-	-	-	-	-	-	-
2892	0	-	-	-	-	-	-	-
2029	0	-	-	-	-	-	-	-

[1] Number of samples at or below detection limit (assumed to be zero).
[2] Number of samples above Provincial Water Quality Objectives (PWQO).
* Chlorination at Main STP discontinued in October.

TEMPERATURE (°C) AT 0.5 and 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	9	13.9	12.5	6.1	6.4	22.1
1419	13	15.0	13.1	4.3	11.0	23.5
2877	10	14.1	13.5	6.0	5.9	22.5
2909	9	13.2	12.9	7.0	5.7	22.3
2891	9	13.4	14.2	6.9	5.8	22.2
2886	9	14.0	13.6	5.9	6.0	22.2
1536	9	14.0	13.4	6.0	6.3	22.3
2878	10	14.7	12.6	6.4	7.1	23.1
2910	8	11.8	9.5	6.0	6.3	21.5
2209	15	14.4	13.5	6.4	6.1	22.5
2892	15	14.3	13.3	6.5	5.8	23.0
2029	9	13.3	14.3	7.0	5.9	22.6
6.0 m						
2036	0	-	-	-	-	-
1419	7	8.5	8.4	2.6	6.0	13.2
2877	2	9.7	9.7	4.7	6.3	13.0
2909	3	8.8	5.9	5.1	5.8	14.6
2891	0	-	-	-	-	-
2886	2	9.5	9.5	3.9	6.7	12.2
1536	0	-	-	-	-	-
2878	2	9.9	9.9	4.0	7.1	12.7
2910	1	24.2	-	-	-	-
2209	1	22.1	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

FIELD-MEASURED TOTAL AMMONIA (mg/L) AT 0.5 AND 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	N[3]
0.5 m									
2036	7	0.9	0.8	0.6	0.1	1.6	0	3	4
1419	12	6.8	7.7	2.2	2.4	9.2	0	6	8
2877	8	0.7	0.3	0.8	0.010	1.9	0	3	5
2909	7	0.7	0.6	0.7	0.007	1.9	0	3	5
2891	6	0.4	0.01	1.0	0.005	2.4	0	1	5
2886	7	0.03	0.02	0.02	0.015	0.06	0	0	5
1536	6	0.04	0.03	0.04	0.010	0.1	0	0	5
2878	8	1.5	0.9	1.8	0.004	4.5	0	1	5
2910	6	0.5	0.4	0.6	0.010	1.4	0	1	4
2209	13	0.3	0.1	0.4	0.002	1.0	0	3	11
2892	13	0.1	0.01	0.1	0.006	0.3	0	0	11
2029	7	0.05	0.03	0.1	0.002	0.2	0	0	6
6.0 m									
2036	0	-	-	-	-	-	-	-	0
1419	8	0.3	0.3	0.2	0.07	0.6	0	0	3
2877	2	0.1	0.1	0.1	0.05	0.2	-	-	0
2909	3	0.1	0.1	0.1	0.05	0.2	-	-	0
2891	0	-	-	-	-	-	-	-	0
2886	1	0.02	-	-	-	-	-	-	0
1536	0	-	-	-	-	-	-	-	0
2878	2	0.5	0.5	0.5	0.1	0.8	-	-	0
2910	1	0.1	-	-	-	-	-	-	0
2209	1	0.02	-	-	-	-	-	-	0
2892	0	-	-	-	-	-	-	-	0
2029	0	-	-	-	-	-	-	-	0

[1] Number of samples below detection limit.
[2] Number of samples above Provincial Water Quality Objectives (PWQO).
[3] Number of samples compared to PWQO (temperature and pH required).

LAB-MEASURED TOTAL AMMONIA (mg/L) AT 0.5 AND 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQO[2]	N[3]
0.5 m									
2036	4	0.2	0.2	0.2	0.03	0.5	1	0	1
1419	4	7.2	8.0	3.8	2.0	10.8	-	-	0
2877	4	0.5	0.01	1.0	0.006	2.1	0	1	1
2909	4	0.01	0.01	0.01	0.004	0.03	1	0	1
2891	4	0.01	0.01	0.01	0.001	0.03	1	0	1
2886	4	0.04	0.04	0.03	0.001	0.1	0	0	1
1536	4	0.04	0.04	0.03	0.006	0.1	0	0	1
2878	4	2.4	1.7	2.6	0.025	6.2	1	0	1
2910	4	1.1	0.8	1.2	0.025	2.8	1	0	1
2209	4	0.2	0.2	0.2	0.025	0.4	1	0	1
2892	4	0.01	0.01	0.01	0.002	0.03	1	0	1
2029	3	0.01	0.01	0.004	0.002	0.03	-	-	0
6.0 m									
2036	0	-	-	-	-	-	-	-	0
1419	0	-	-	-	-	-	-	-	0
2877	0	-	-	-	-	-	-	-	0
2909	0	-	-	-	-	-	-	-	0
2891	0	-	-	-	-	-	-	-	0
2886	0	-	-	-	-	-	-	-	0
1536	0	-	-	-	-	-	-	-	0
2878	0	-	-	-	-	-	-	-	0
2910	0	-	-	-	-	-	-	-	0
2209	0	-	-	-	-	-	-	-	0
2892	0	-	-	-	-	-	-	-	0
2029	0	-	-	-	-	-	-	-	0

[1] Number of samples below detection limit.
[2] Number of samples above Provincial Water Quality Objectives (PWQO).
[3] Number of samples compared to PWQO (temperature and pH required).

PHOSPHORUS (mg/L) AT 0.5 and 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX	DL[1]	PWQG[2]
0.5 m								
2036	10	0.09	0.07	0.06	0.03	0.21	0	10
1419	14	0.18	0.13	0.10	0.09	0.39	0	14
2877	10	0.06	0.03	0.06	0.01	0.17	0	5
2909	10	0.04	0.03	0.04	0.01	0.12	1	5
2891	10	0.03	0.01	0.04	0.01	0.09	2	3
2886	10	0.03	0.01	0.03	0.002	0.09	1	3
1536	10	0.03	0.01	0.03	0.004	0.09	0	2
2878	10	0.05	0.05	0.03	0.01	0.10	0	8
2910	9	0.04	0.03	0.03	0.01	0.09	1	6
2209	15	0.03	0.02	0.03	0.003	0.10	1	7
2892	15	0.03	0.01	0.03	0.001	0.09	2	4
2029	9	0.01	0.01	0.01	0.004	0.03	1	1
6.0 m								
`036	0	-	-	-	-	-	-	-
1419	4	0.05	0.05	0.02	0.03	0.07	0	4
2877	0	-	-	-	-	-	-	-
2909	0	-	-	-	-	-	-	-
2891	0	-	-	-	-	-	-	-
2886	1	0.03	-	-	-	-	0	1
1536	0	-	-	-	-	-	-	-
2878	0	-	-	-	-	-	-	-
2910	0	-	-	-	-	-	-	-
2209	0	-	-	-	-	-	-	-
2892	0	-	-	-	-	-	-	-
2029	0	-	-	-	-	-	-	-

[1] Number of samples below detection limit.
[2] Number of samples above Provincial Water Quality Guidelines (PWQG).

PH AT 0.5 and 6 M DEPTHS, ANNUAL MEAN, 1987

STN	N	MEAN	MEDIAN	SD	MIN	MAX
0.5 m						
2036	5	8.1	8.0	0.1	8.0	8.2
1419	9	7.3	7.4	0.3	6.6	7.6
2877	6	8.0	8.0	0.4	7.5	8.5
2909	6	8.0	8.1	0.3	7.4	8.3
2891	6	8.2	8.3	0.3	7.7	8.5
2886	6	8.3	8.4	0.3	7.6	8.5
1536	6	8.3	8.4	0.4	7.6	8.5
2878	6	8.2	8.3	0.4	7.6	8.6
2910	5	8.2	8.2	0.4	7.8	8.7
2209	12	8.3	8.4	0.2	7.7	8.5
2892	12	8.3	8.4	0.2	7.7	8.6
2029	6	8.5	8.5	0.1	8.4	8.7
6.0 m						
2036	0	-	-	-	-	-
1419	3	5.9	7.7	3.4	2.0	7.9
2877	0	-	-	-	-	-
2909	0	-	-	-	-	-
2891	0	-	-	-	-	-
2886	1	8.4	-	-	-	-
1536	0	-	-	-	-	-
2878	0	-	-	-	-	-
2910	0	-	-	-	-	-
2209	0	-	-	-	-	-
2892	0	-	-	-	-	-
2029	0	-	-	-	-	-

ANNUAL MEAN

HEAVY METALS

1987

MAIN STP (STATION 22) FINAL EFFLUENT
QUALITY, ANNUAL MEAN, 1987

PAR[1]	N	MEAN	MEDIAN	SD	MIN	MAX	DL[2]	IWDG[3]
Time (hours)	25	10.6	10.7	1.8	8.3	13.7		
Cadmium (µg/L)	25	1.10	0.100	1.85	0.100	7.00	1	4
Chromium	24	0.034	0.020	0.049	0.010	0.240	0	0
Copper	23	0.030	0.015	0.046	0.010	0.225	0	0
Iron	25	1.864	0.875	3.828	0.250	19.50	0	-
Mercury (µg/L)	24	0.068	0.038	0.120	0.010	0.610	0	0
Manganese	24	0.078	0.065	0.025	0.050	0.150	0	-
Nickel	24	0.038	0.030	0.018	0.020	0.090	0	0
Lead	25	0.015	0.010	0.017	0.010	0.085	2	0
Zinc	22	0.066	0.030	0.113	0.010	0.525	0	0

[1] Parameter units are mg/L unless otherwise indicated.
[2] Number of samples below detection limit.
[3] Number of samples above Industrial Waste Discharge Guidelines (IWDG).

CADMIUM (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	0	8	.	.	.	.
2886	0	9	.	.	.	.
2891	0	9	.	.	.	.
2909	0	8	.	.	.	.
2877	0	9	.	.	.	.
1419	10	23	.0005	.0002	.0010	.0130
2878	0	9	.	.	.	.
2910	1	8	.	.	.	.0110
2209	0	16	.	.	.	.
2892	1	14	.	.	.	.0007
2029	1	9	.	.	.	.
2036	2	9	.	.	.	.0005
1419 (6m)	1	6	.	.	.	.0090

CHROMIUM (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	8	8	.0051	.0019	.0133	.036
2886	8	9	.0021	.0012	.0034	.011
2891	7	9	.0019	.0011	.0032	.009
2909	7	8	.0020	.0013	.0030	.006
2877	9	9	.0022	.0017	.0029	.004
1419	23	23	.0087	.0073	.0104	.021
2878	9	9	.0053	.0027	.0106	.035
2910	7	8	.0046	.0019	.0109	.015
2209	13	16	.0025	.0014	.0046	.057
2892	10	14	.0014	.0010	.0020	.007
2029	8	9	.0011	.0010	.0012	.002
2036	9	9	.0050	.0028	.0090	.015
1419 (6m)	6	6	.0027	.0014	.0053	.011

COPPER (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > OL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	8	8	.0011	.0010	.0013	.002
2886	8	9	.0010	.0010	.0010	.001
2891	7	9	.0012	.0009	.0016	.004
2909	7	8	.0013	.0011	.0017	.002
2877	9	9	.0018	.0014	.0023	.004
1419	23	23	.0064	.0052	.0079	.015
2878	9	9	.0020	.0015	.0027	.004
2910	7	8	.0020	.0011	.0034	.010
2209	13	16	.0012	.0010	.0014	.003
2892	10	14	.0010	.0010	.0010	.001
2029	5	9	.0010	.0010	.0010	.001
2036	9	9	.0041	.0025	.0066	.013
1419 (6m)	4	6	.0017	.0007	.0046	.010

IRON (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N >DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	8	8	.0255	.0193	.0337	.036
2886	9	9	.0287	.0190	.0432	.080
2891	9	9	.0423	.0197	.0909	.370
2909	8	8	.0862	.0501	.1485	.190
2877	9	9	.1130	.0616	.2073	.220
1419	23	23	.4695	.3861	.5708	1.300
2878	9	9	.1355	.0860	.2137	.350
2910	8	8	.0688	.0464	.1019	.170
2209	16	16	.0820	.0503	.1337	.880
2892	14	14	.0275	.0204	.0371	.077
2029	7	9	.0175	.0045	.0682	.040
2036	9	9	.4228	.2338	.7647	1.900
1419 (6m)	6	6	.1895	.1322	.2715	.350

MERCURY (μg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	0	9	.	.	.	.
2886	1	9	.	.	.	.010
2891	3	9	.0087	.0046	.0163	.040
2909	4	9	.0100	.0100	.0100	.010
2877	4	9	.0094	.0074	.0119	.020
1419	22	23	.0277	.0210	.0365	.230
2878	5	9	.0100	.0083	.0121	.020
2910	3	8	.0100	.0100	.0100	.010
2209	1	15	.	.	.	.010
2892	1	14	.	.	.	.010
2029	0	9	.	.	.	.
2036	5	9	.0104	.0077	.0141	.030
1419 (6m)	0	7	.	.	.	.

MANGANESE (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	8	8	.0029	.0020	.0043	.006
2886	9	9	.0030	.0020	.0045	.010
2891	9	9	.0026	.0017	.0042	.012
2909	8	8	.0050	.0034	.0073	.012
2877	9	9	.0067	.0042	.0106	.015
1419	23	23	.0260	.0234	.0290	.040
2878	9	9	.0088	.0057	.0136	.026
2910	8	8	.0054	.0035	.0083	.020
2209	16	16	.0033	.0025	.0042	.007
2892	14	14	.0021	.0017	.0026	.004
2029	8	9	.0017	.0013	.0020	.003
2036	9	9	.0103	.0075	.0143	.026
1419 (6m)	6	6	.0066	.0047	.0093	.014

NICKEL (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN	CONF. INTERVAL MAX	OBSERVED MAX
1536	2	9	.	.	.	.002
2886	5	9	.0020	.0020	.0020	.002
2891	4	9	.0019	.0014	.0026	.005
2909	7	8	.0024	.0020	.0030	.005
2877	7	9	.0030	.0021	.0043	.008
1419	23	23	.0118	.0102	.0137	.042
2878	7	9	.0044	.0027	.0073	.011
2910	4	8	.0045	.0010	.0195	.033
2209	7	16	.0020	.0020	.0020	.002
2892	6	14	.0020	.0020	.0020	.002
2029	5	9	.0020	.0020	.0020	.002
2036	7	9	.0028	.0023	.0035	.004
1419 (6m)	3	6	.0031	.0006	.0161	.026

LEAD (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN.	CONF. INTERVAL MAX	OBSERVED MAX
1536	2	8	.	.	.	.004
2886	2	9	.	.	.	.004
2891	4	9	.0032	.0024	.0044	.006
2909	2	8	.	.	.	.005
2877	2	9	.	.	.	.004
1419	11	23	.0043	.0030	.0060	.011
2878	2	9	.	.	.	.004
2910	1	8	.	.	.	.021
2209	0	16	.	.	.	.
2892	0	14	.	.	.	.
2029	1	9	.	.	.	.003
2036	5	9	.0044	.0026	.0074	.011
1419 (6m)	1	6	.	.	.	.008

ZINC (mg/L)
MAXIMUM LIKELIHOOD ESTIMATE OF ANNUAL MEAN, 1987
SURFACE VALUES (0.5 m) UNLESS OTHERWISE STATED

STN	N > DL	N	MEAN CONCN.	CONF. INTERVAL MIN.	CONF. INTERVAL MAX	OBSERVED MAX
1536	4	8	.0016	.0011	.0024	.005
2886	4	9	.0021	.0008	.0059	.021
2891	2	9	.	.	.	.002
2909	3	8	.0019	.0012	.0030	.004
2877	6	9	.0027	.0020	.0038	.006
1419	20	23	.0106	.0072	.0157	.020
2878	5	9	.0024	.0017	.0035	.006
2910	6	8	.0025	.0012	.0053	.012
2209	7	16	.0017	.0011	.0025	.012
2892	6	14	.0015	.0011	.0022	.008
2029	3	9	.0013	.0009	.0019	.004
2036	6	9	.0071	.0015	.0338	.031
1419 (6m)	4	6	.0028	.0009	.0085	.014

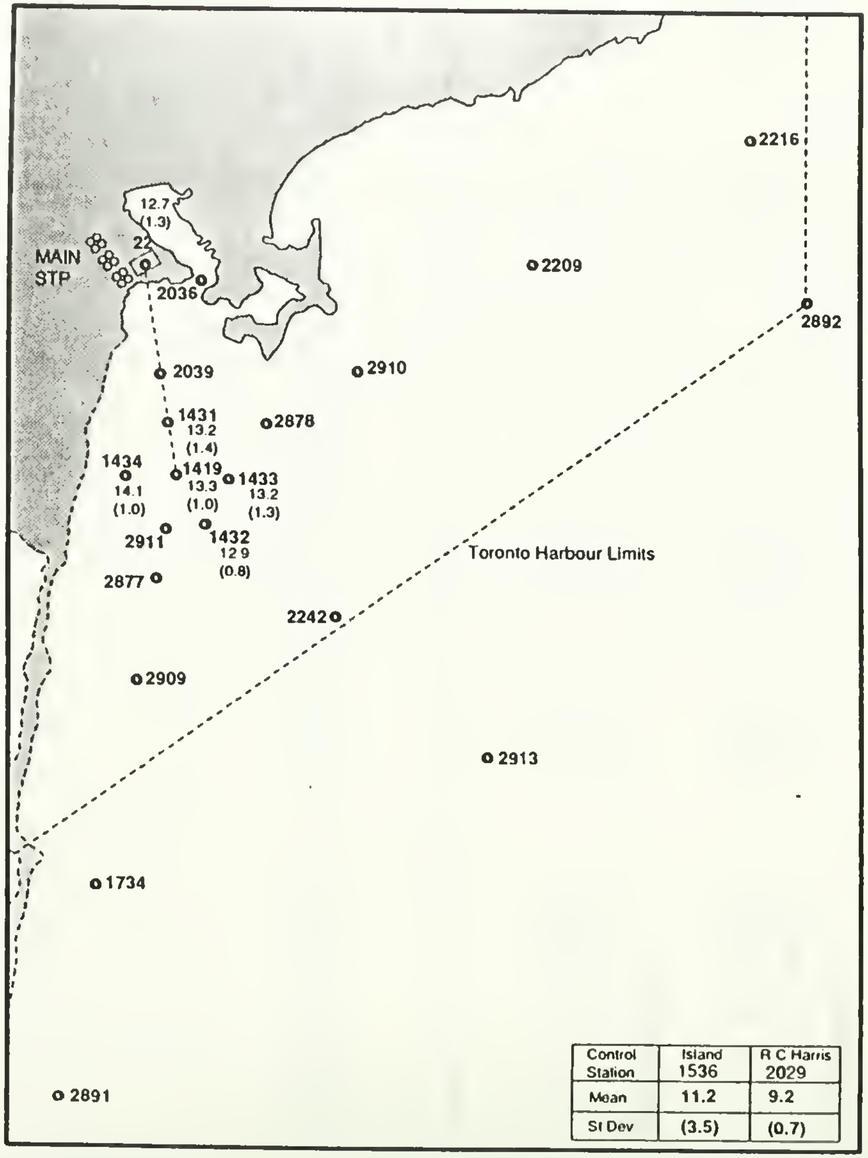
APPENDIX 3

CONCENTRATION MAPS AND DILUTION FACTORS FOR 1986

TABLE A3.1: DILUTION FACTORS[1] FOR DIFFERENT CHEMICALS AT SELECTED STATIONS IN 1986

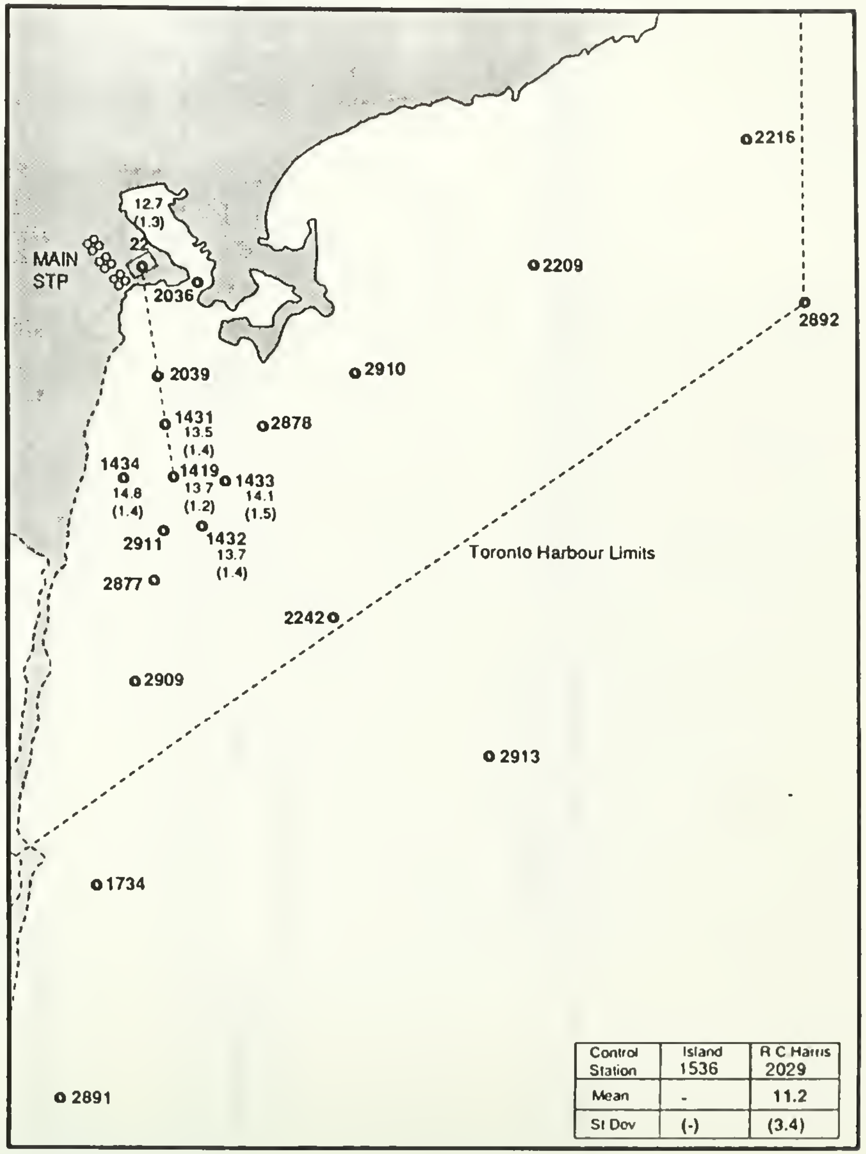
PARAMETER	1419	1431	1432	1433	1434
Field Ammonia:					
o 0.5 m depth	0.33	0.12	0.03	0.09	0.07
o 6.0 m depth	0.08	0.005	0	0	0.005
Lab Ammonia:					
o 0.5 m depth	0.31	0.11	0.03	0.08	0.07
o 6.0 m depth	0.06	0.01	0	0.01	0.005
Phosphorus:					
o 0.5 m depth	0.22	0.04	0.01	0.05	0.06
o 6.0 m depth	0	0	0	0	0

[1] Dilution Factor = (Concentration-Background)/(Source-Background)



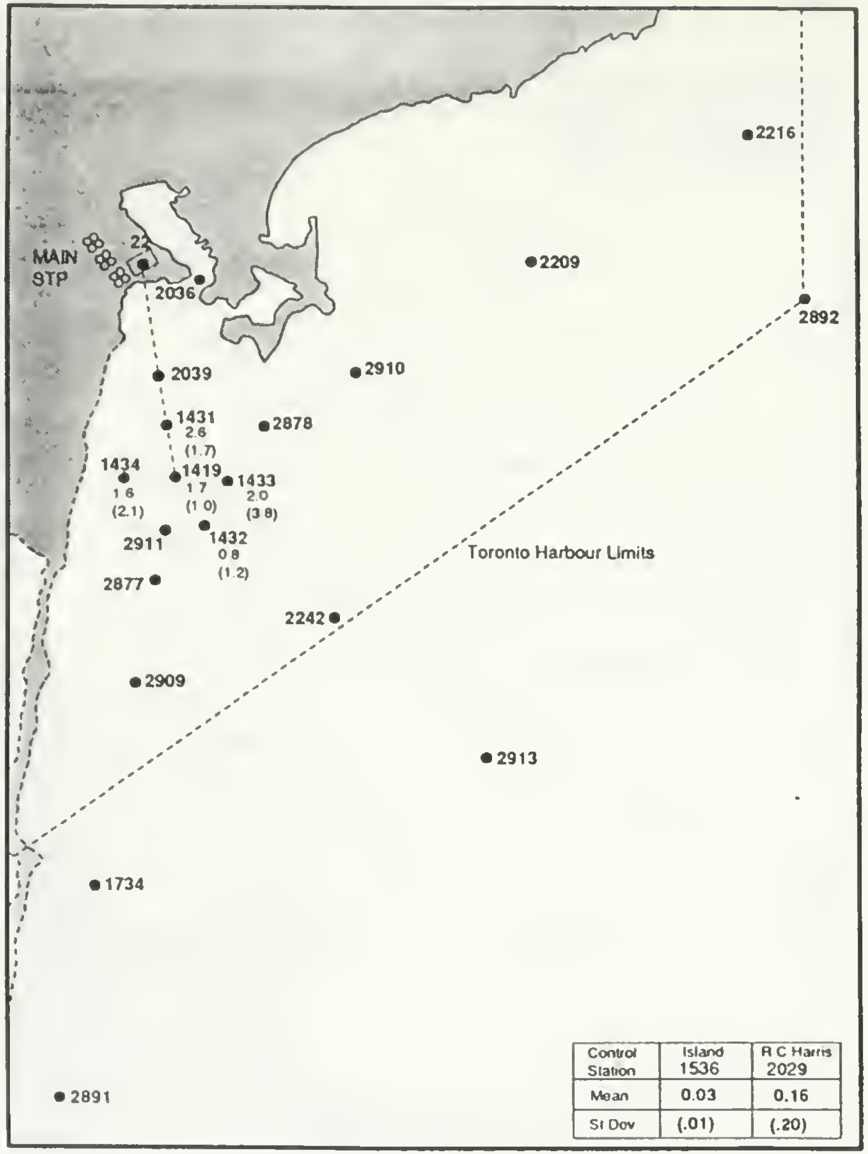
Control Station	Island 1536	R C Harris 2029
Mean	11.2	9.2
St Dev	(3.5)	(0.7)

FIGURE A3.1
Sampling Time (Hrs) at 0.5m Depth in 1986



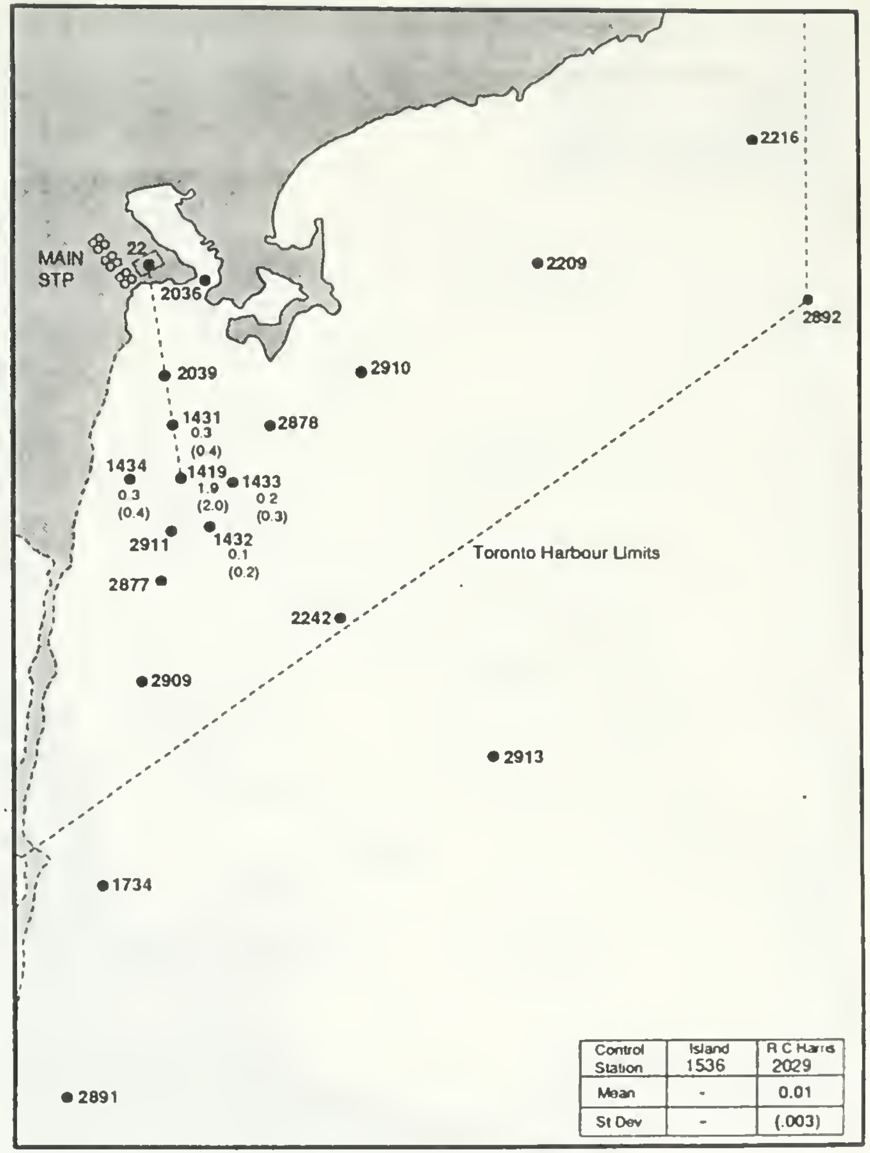
Control Station	Island 1536	R C Harris 2029
Mean	-	11.2
St Dev	(-)	(3.4)

FIGURE A3.2
Sampling Time (Hrs) at 6m Depth in 1986



Control Station	Island 1536	R C Harris 2029
Mean	0.03	0.16
St Dev	(.01)	(.20)

FIGURE A3.3
Field Ammonia (mg/L) at 0.5m Depth in 1986



Control Station	Island 1536	R C Harris 2029
Mean	-	0.01
St Dev	-	(.003)

FIGURE A3.4
Field Ammonia (mg/L) at 6m Depth in 1986

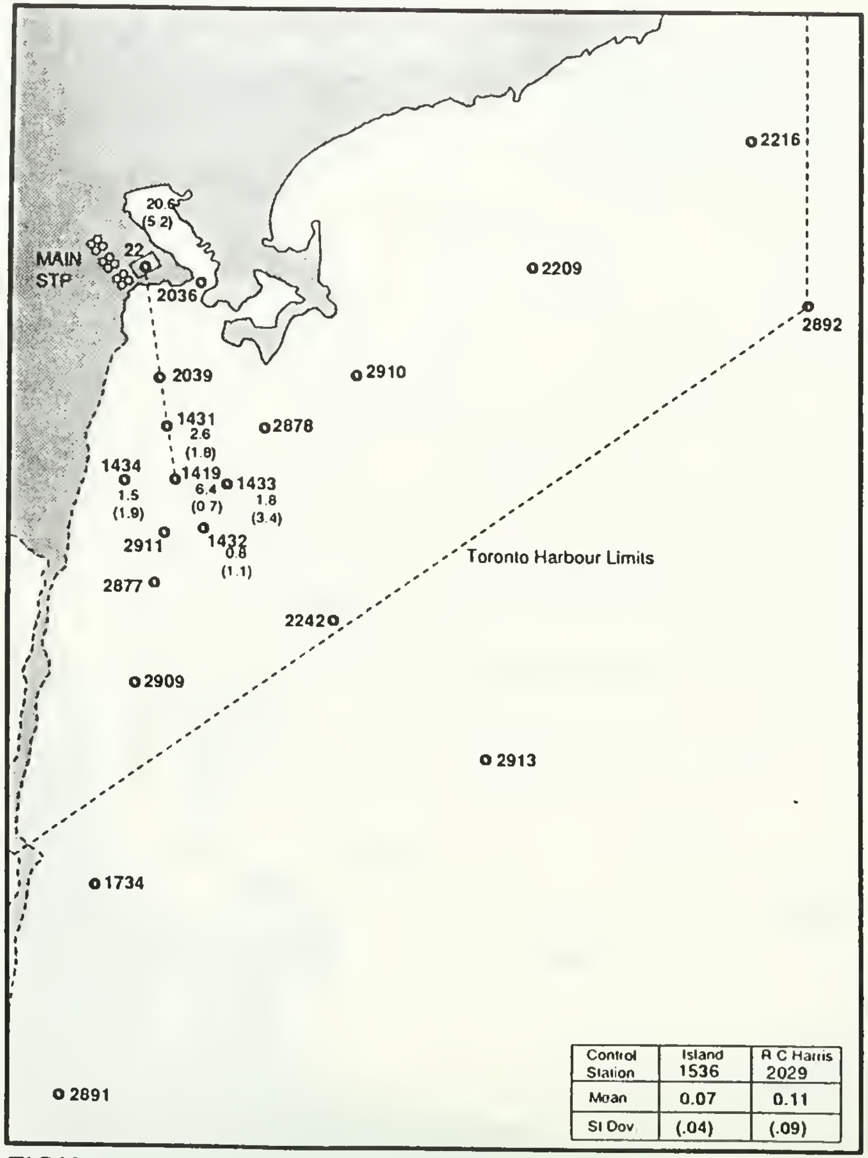


FIGURE A3.5
Lab Ammonia (mg/L) at 0.5m Depth in 1986

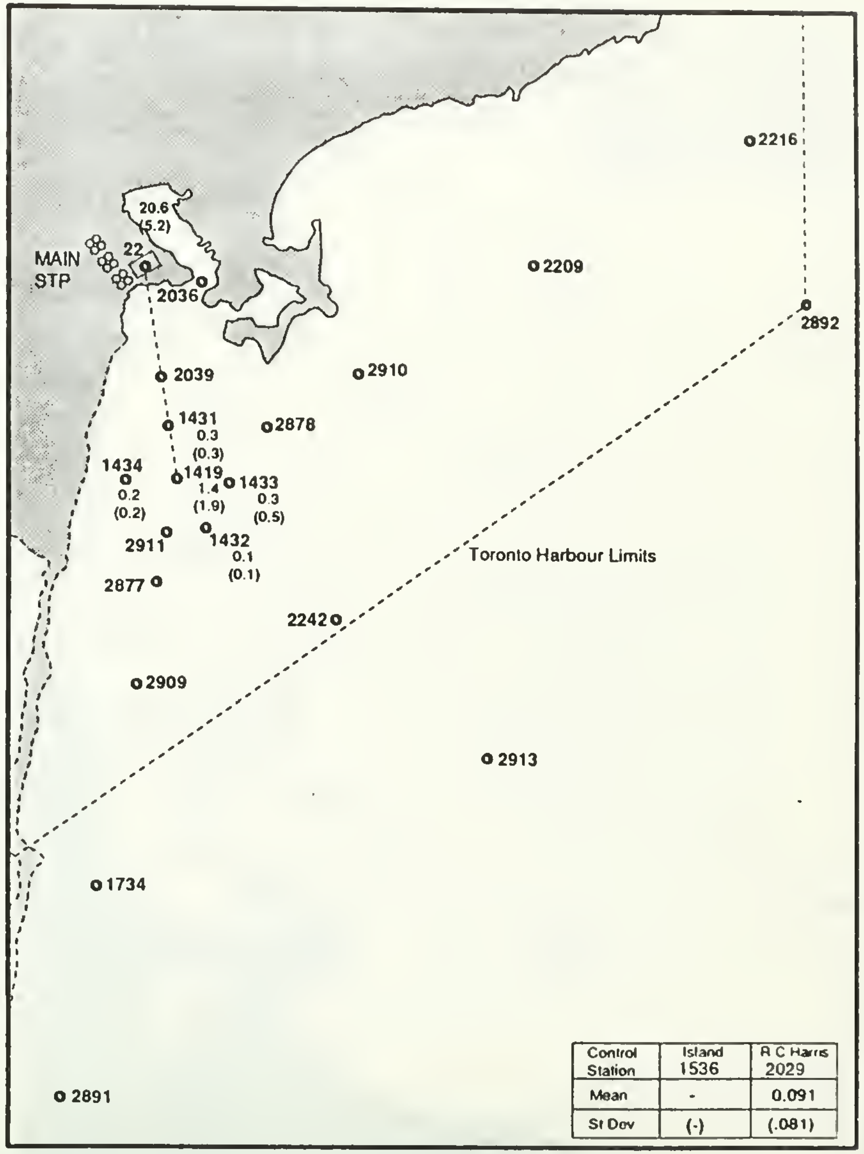


FIGURE A3.6
Lab Ammonia (mg/L) at 6m Depth in 1986

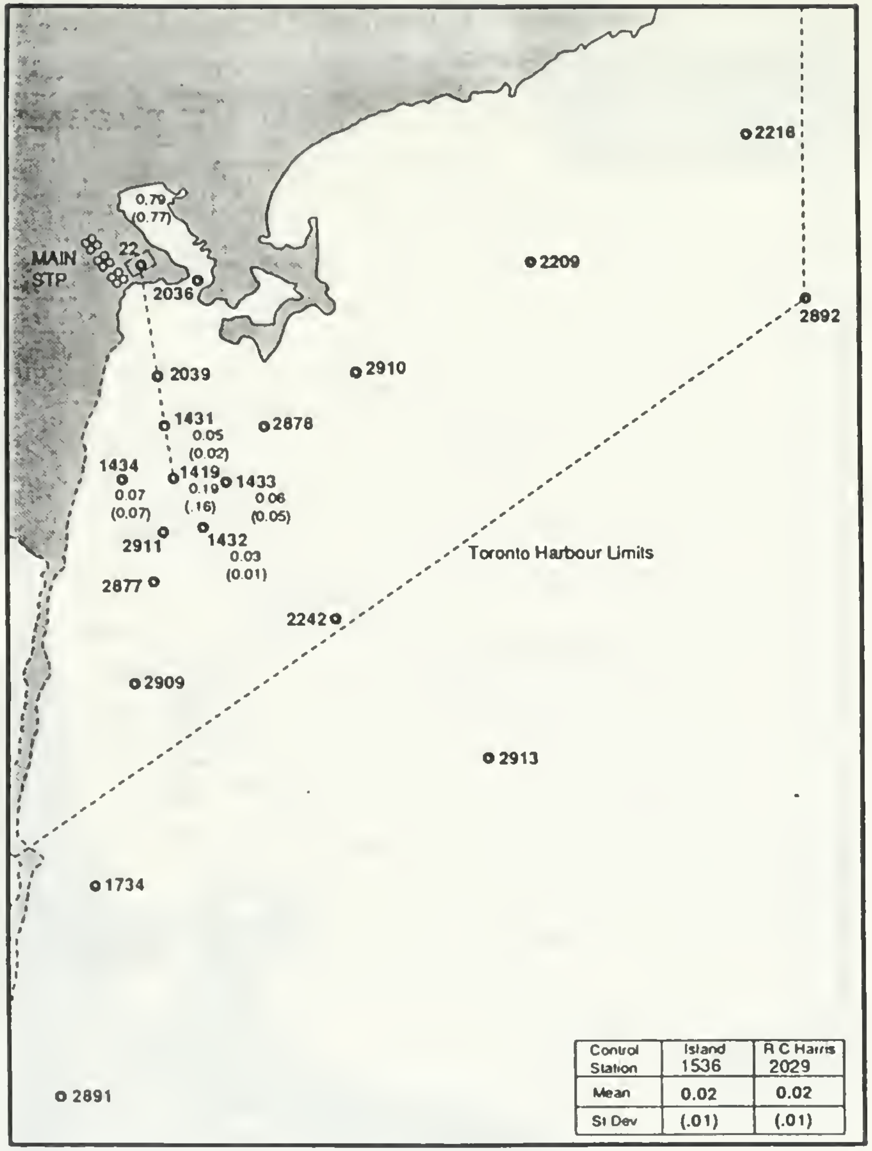


FIGURE A3.7
Phosphorus (mg/L) at 0.5m Depth in 1986

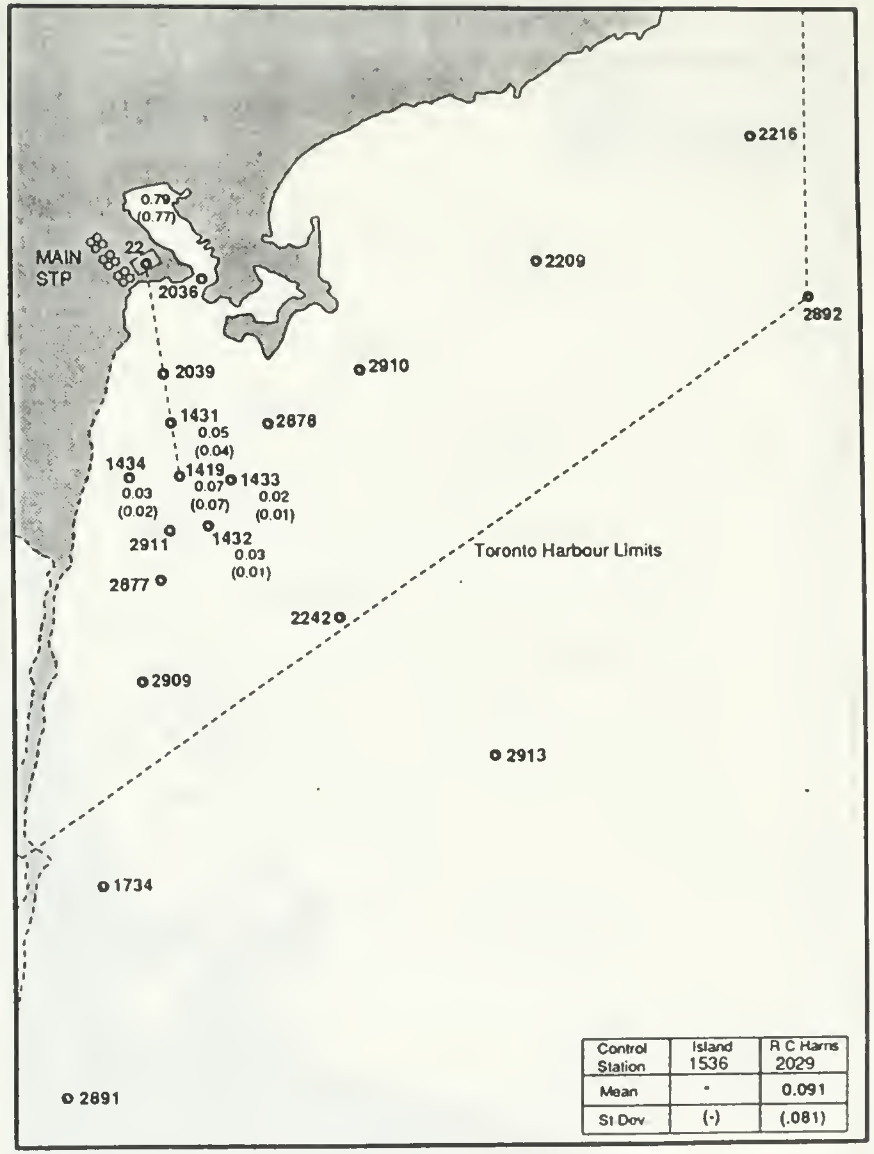
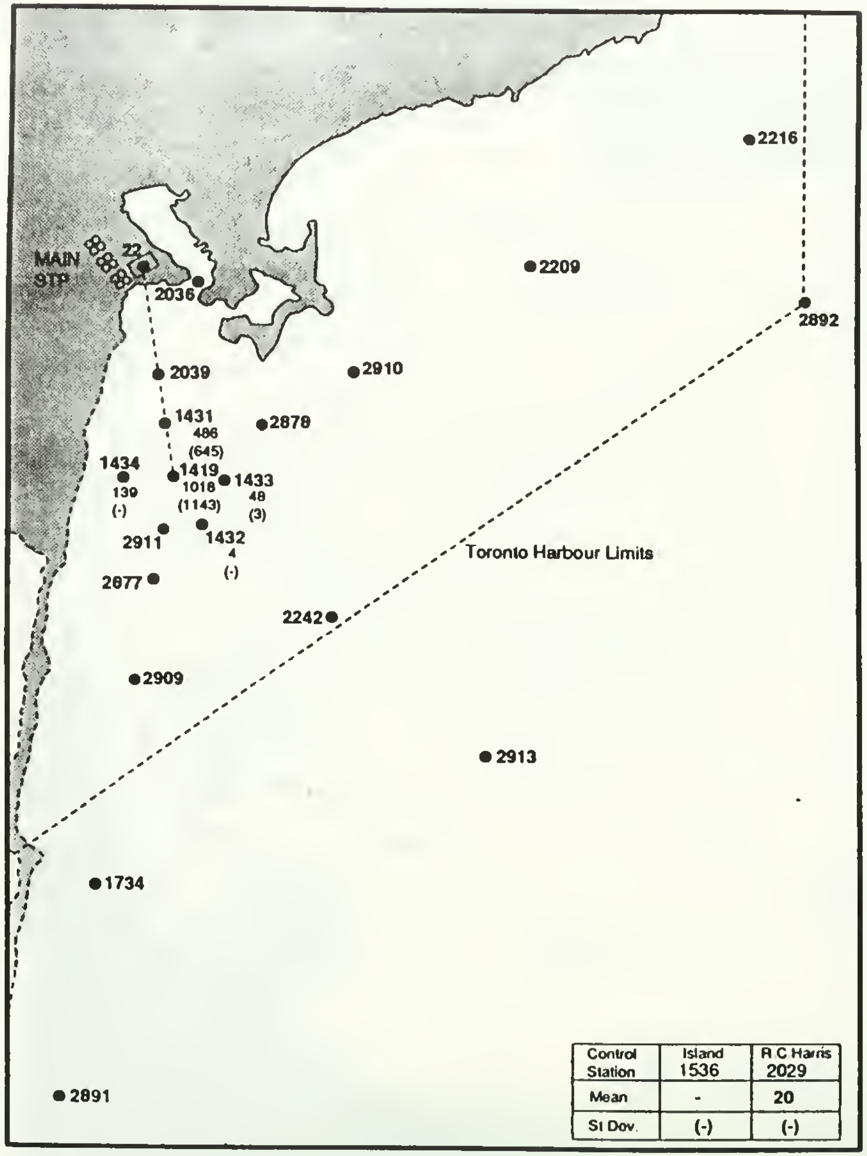
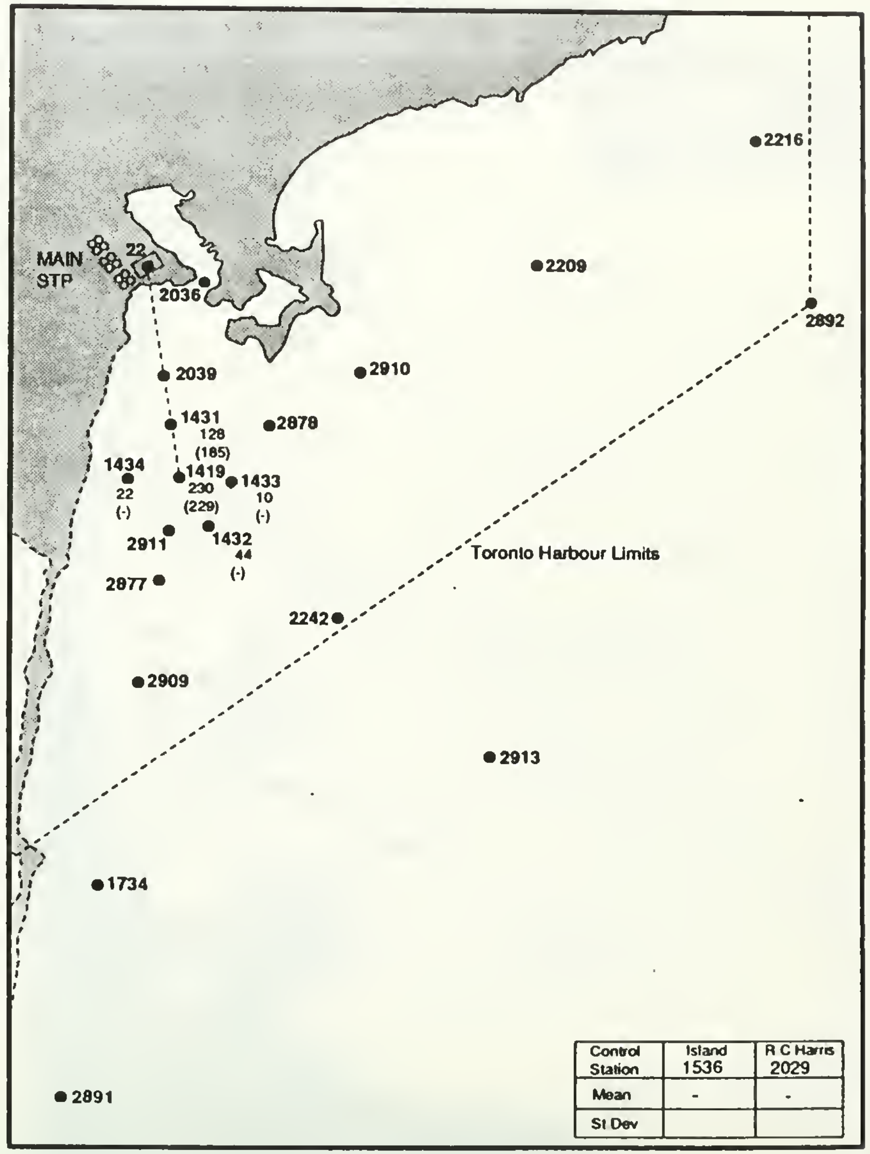


FIGURE A3.8
Phosphorus (mg/L) at 6m Depth in 1986



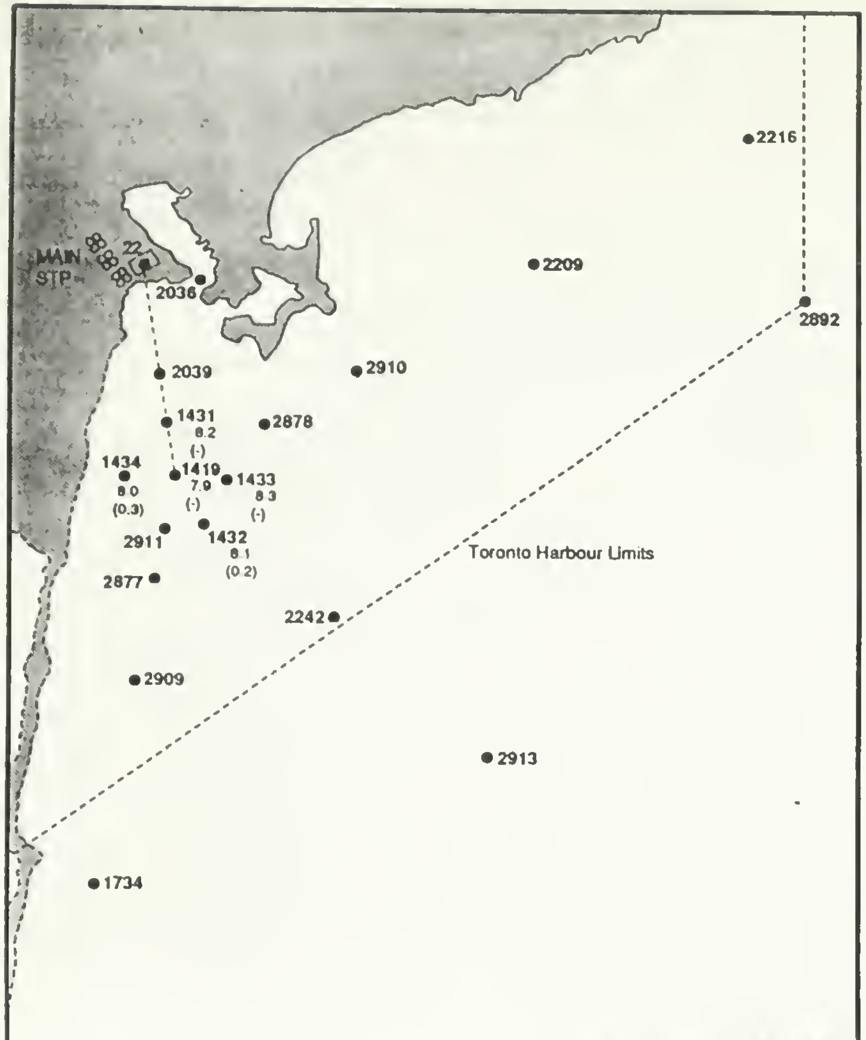
Control Station	Island 1536	R C Harris 2029
Mean	-	20
St Dev.	(-)	(-)

FIGURE A 3.9
Field Chlorine (ug/L) at 0.5m Depth in 1986



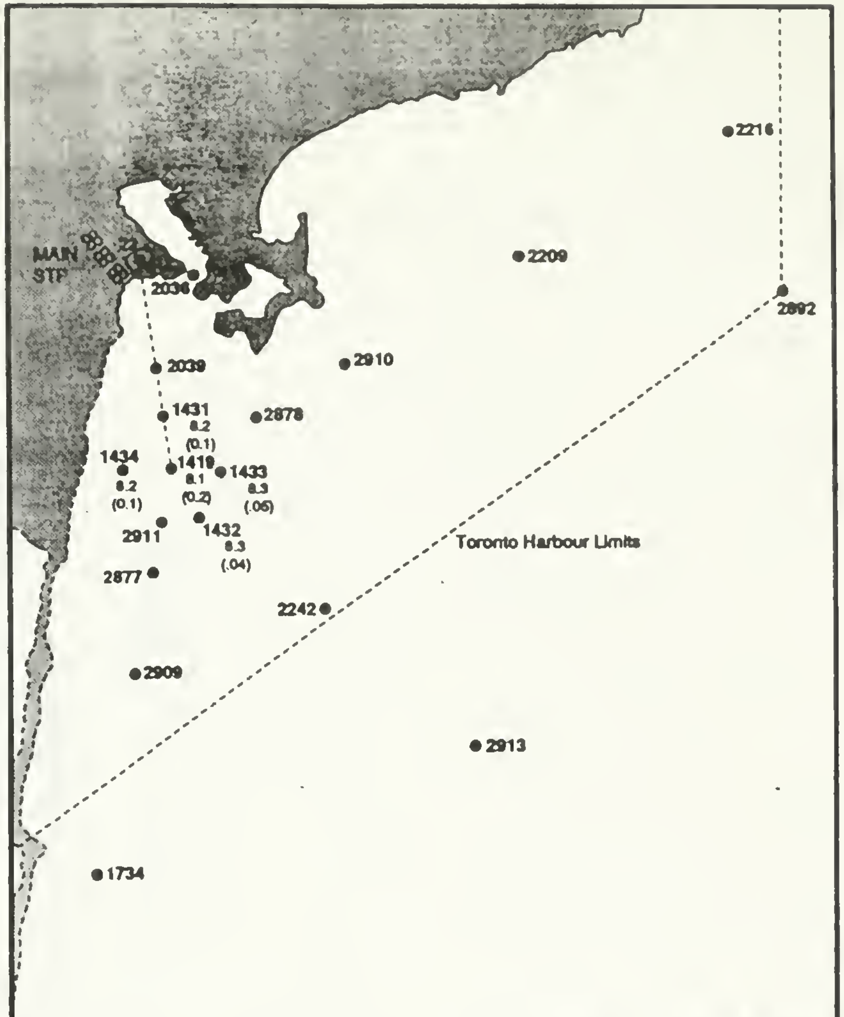
Control Station	Island 1536	R C Harris 2029
Mean	-	-
St Dev		

FIGURE A 3.10
Field Chlorine (ug/L) at 6m Depth in 1986



Control Station	Island 1536	R C Harris 2029
Mean	8.4	8.5
St Dev	(-)	(-)

FIGURE A 3.I1
pH at 0.5m Depth in 1986



Control Station	Island 1536	R C Harris 2029
Mean	-	8.26
St.Dev	(-)	(.07)

FIGURE A 3.I2
pH at 6m Depth in 1986

APPENDIX 4

COMPARISON OF METHODS FOR CENSORED DATA HANDLING

APPENDIX 4: COMPARISON OF METHODS FOR CENSORED DATA HANDLING

A number of methods have been used for estimation of mean and variance from left- censored data sets. A data set is left-censored when contaminant concentrations in some of the samples are lower than the detection limit of the analytical instrument used to measure them. Gilbert (1987) describes most of the methods which have been used. Helsel (1986) compares the performance of some of these methods on artificial data sets from different known distributions. We have compared four methods using Main STP effluent data.

Three of the methods compared here involve replacement of the 'non-detect' observation with an estimate of the true value:

1. DL - replacement by face value of detection limit.
2. ½DL - replacement by half the face value.
3. LR - linear regression of measured values on rankits.

The fourth method provides a direct estimate of true mean and variance based on knowledge of the total number of observations and the proportion below the detection limit:

4. ML - maximum likelihood estimation.

Methods 1 and 2 are arbitrary, while 3 and 4 assume normality and strive to optimize the solution to the problem. A consensus seems to be emerging that the maximum likelihood method (Cohen, 1961) is superior, if assumptions are satisfied; however, it is quite sensitive to non-normality. Helsel (1986) notes that the regression method is more robust. Every effort should be made to normalize the data by transformation prior to application of either method. A log transformation is generally suitable for log-normal data.

Table A4.1 shows the estimate of both geometric and arithmetic means for six chemical parameters in Main STP effluent (1987 data) using the four different methods. Original distributions, and distributions after LR replacement, are illustrated in Figures A4.1 through A4.6. The table illustrates several general points.

Firstly, the geometric mean is a biased estimator of the u parameter of the log-normal distribution. There is a low bias which can be quantified as follows (Gilbert, 1987):

$$E(GM) = u \left[\exp\left(- \frac{(n-1)}{2n} \sigma y^2 \right) \right]$$

where: $E(GM)$ = expected value of geometric mean,

u = true mean, and

σy^2 = variance of ln transformed data.

The term in square brackets is the bias factor.

Secondly, the methods are in reasonably close agreement for the degree of censoring encountered in the Main STP effluent. However, the initial assumption of normality or log normality is critical. For example, when log-normality is assumed for ammonia, which is actually closer to normal in distribution, the maximum likelihood method produces a u estimate out of line with other methods, and with a very large variance.

This last point raises some question as to the quantity of data needed to produce a reliable estimate. Helsel (1986) recommends that little can be done with data that is more than 80% censored with n = 10. With the quantity of data available at most individual receiving water stations, after depth partitioning, it will be very difficult to decide with any certainty on the form of the underlying distribution. We suggest that at least 20 measured observations should be available to make this determination.

TABLE A4.1: COMPARISON OF METHODS FOR CENSORED DATA HANDLING OF MAIN STP EFFLUENT CONCENTRATIONS

PARAMETER	h[1]	Geometric Mean[2] DL	½DL	LR	ML	Log-normal[3] u	V
Zinc (mg/L)	0.08	0.026	0.026	0.027	0.026	0.05	0.01
Copper (mg/L)	0.12	0.017	0.016	0.016	0.017	0.02	0.003
NO_2/NO_3 (mg/L)	0.13	0.24	0.24	0.23	0.24	0.77	5.54
Ammonia* (mg/L)	0.02	17.9	17.8	20.0	18.0	26.7	858
Dichloromethane (µg/L)	0.11	4.0	4.0	4.6	4.5	5.5	14.8
Chloroform (µg/L)	0.13	2.1	2.04	2.2	2.2	2.8	5.6

PARAMETER	h[1]	Arithmetic Mean[2] DL	½DL	LR	ML	Normal[3] u	V
Zinc (mg/L)	0.08	0.06	0.06	-	0.05	0.05	0.01
Copper (mg/L)	0.12	0.03	0.03	-	0.03	0.03	0.003
NO_2/NO_3 (mg/L)	0.13	0.82	0.82	-	0.75	0.75	4.79
Ammonia* (mg/L)	0.02	20.4	20.4	20.6	20.4	20.4	32.2
Dichloromethane (µg/L)	0.11	5.4	5.3	-	5.3	5.3	15.1
Chloroform (µg/L)	0.13	2.8	2.7	-	2.6	2.6	3.9

[1]h = proportion of distribution below detection limit.

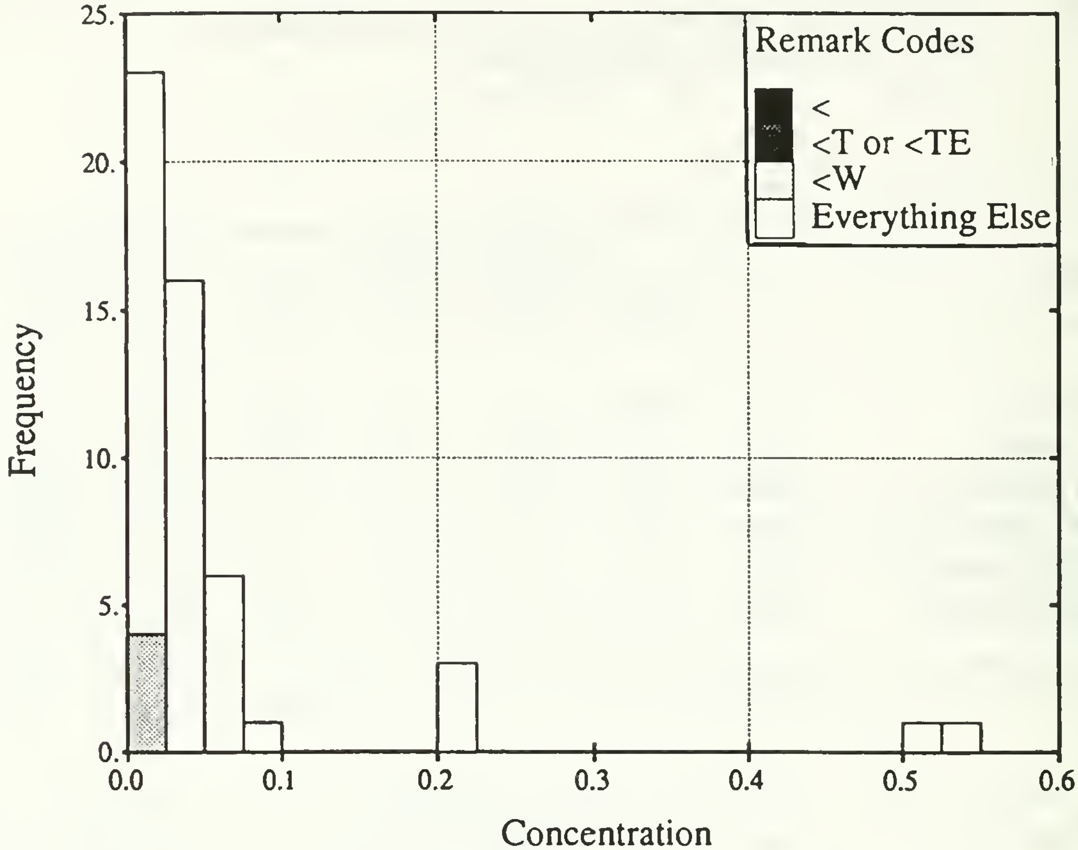
[2]d Geometric mean computed from mean of logs, arithmetic mean from untransformed data, with 'less thans' treated as:

DL = face value of detection limit.
½DL = one-half face value of detection limit.
LR = linear regression estimate of true value.
ML = input to maximum likelihood estimate of mean.

[3] u and V are maximum likelihood estimates of true mean and variance for log-normal or normal distribtuion.

* Ammonia is approximately normal, not log-normal in distribution.

FIGURE A4.1: DISTRIBUTION OF ZINC CONCENTRATION (mg/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT



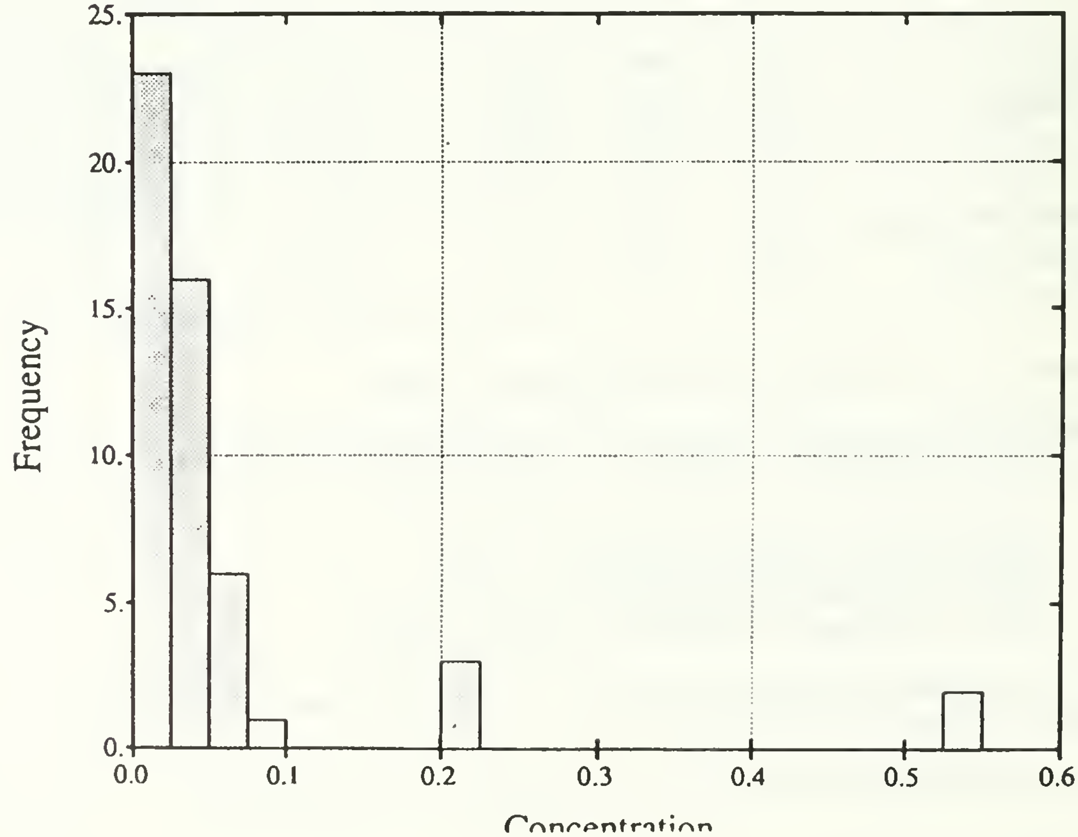
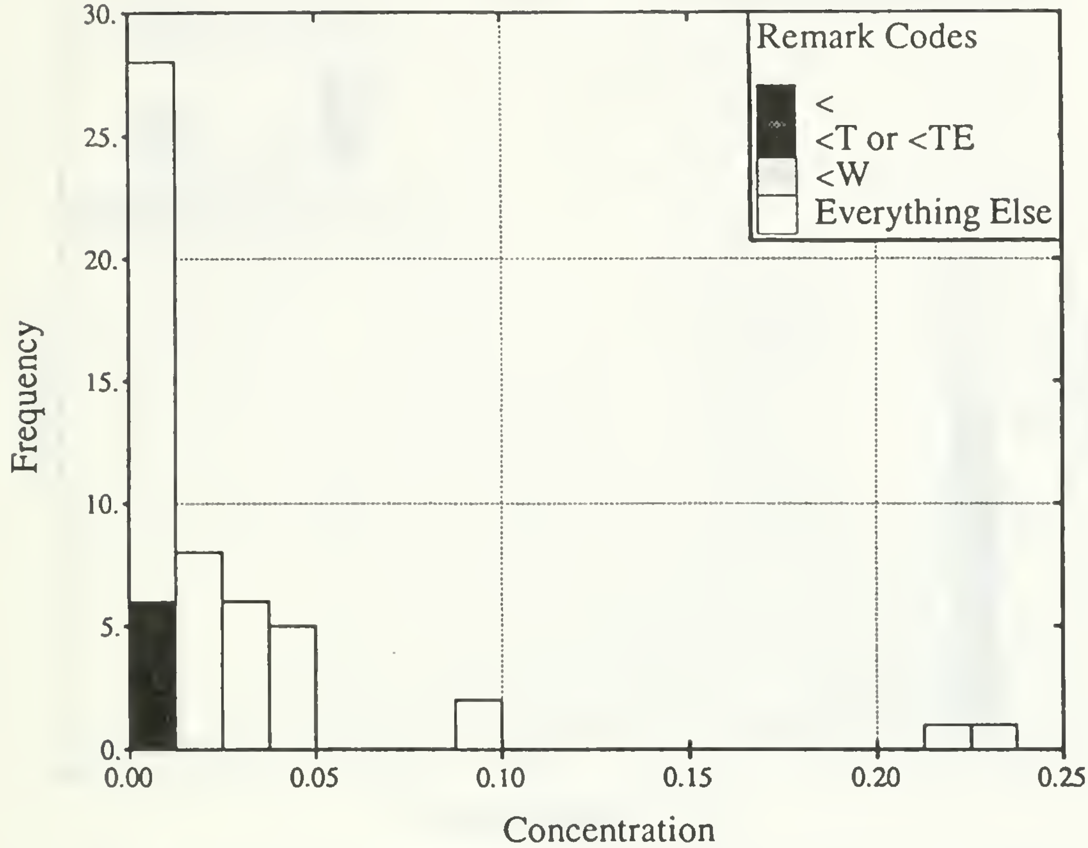


FIGURE A4.2: DISTRIBUTION OF COPPER CONCENTRATION (mg/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT



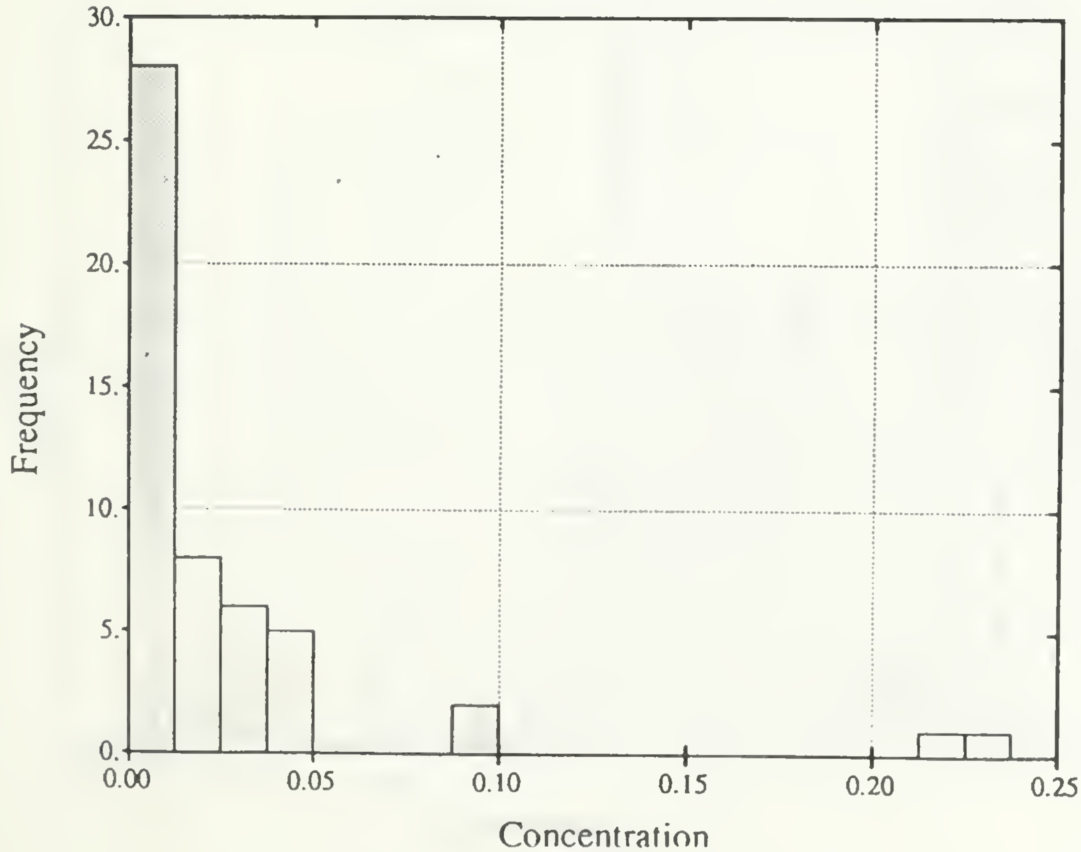
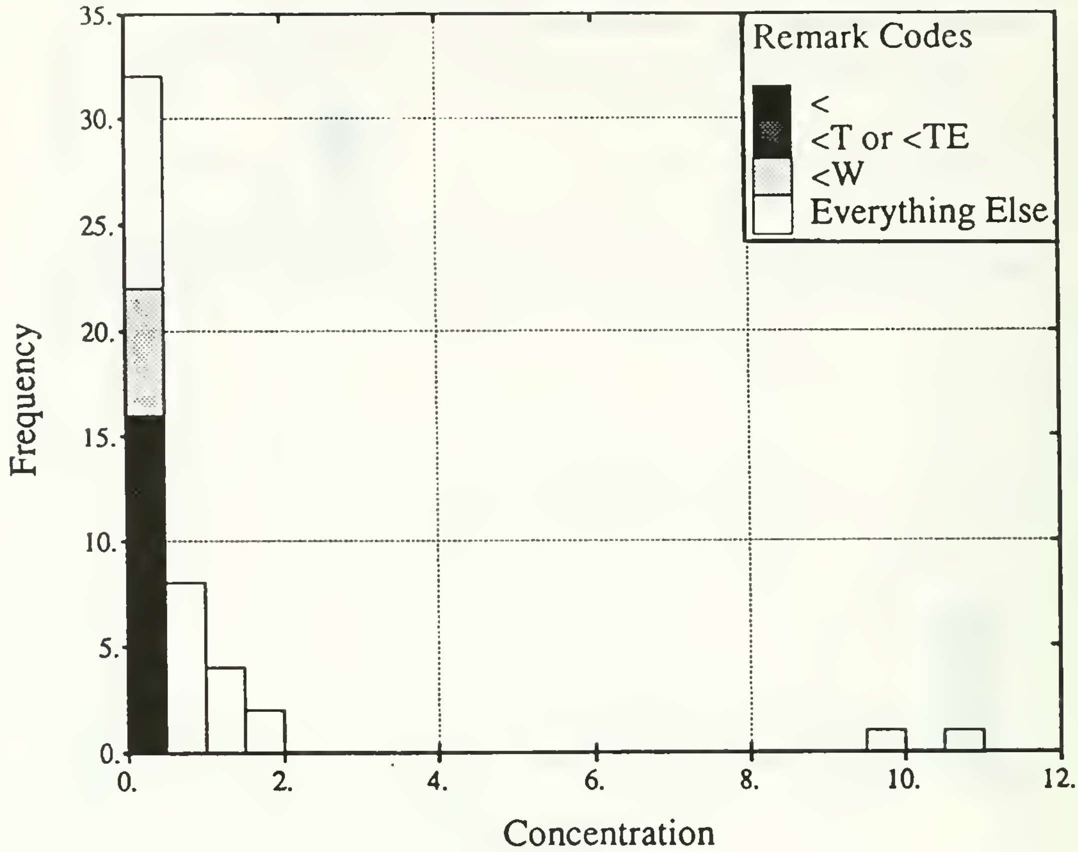


FIGURE A4.3: DISTRIBUTION OF NO_2/NO_3 CONCENTRATION (mg/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT



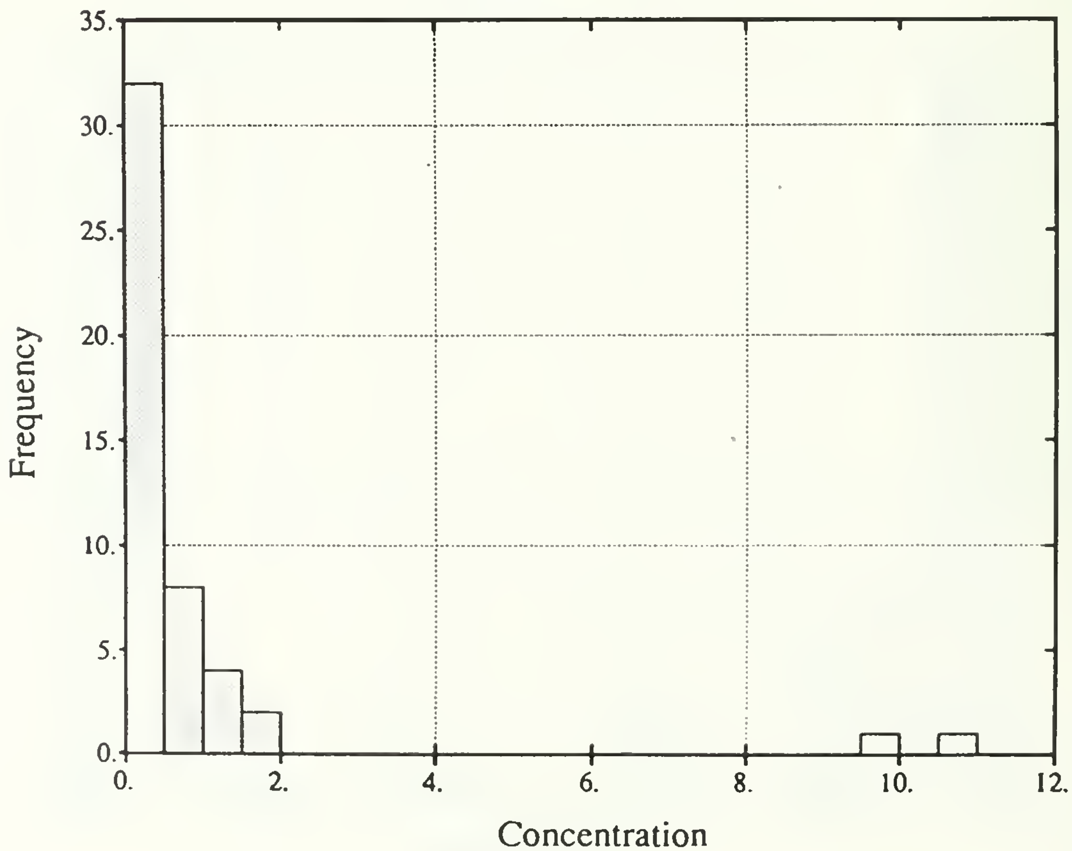
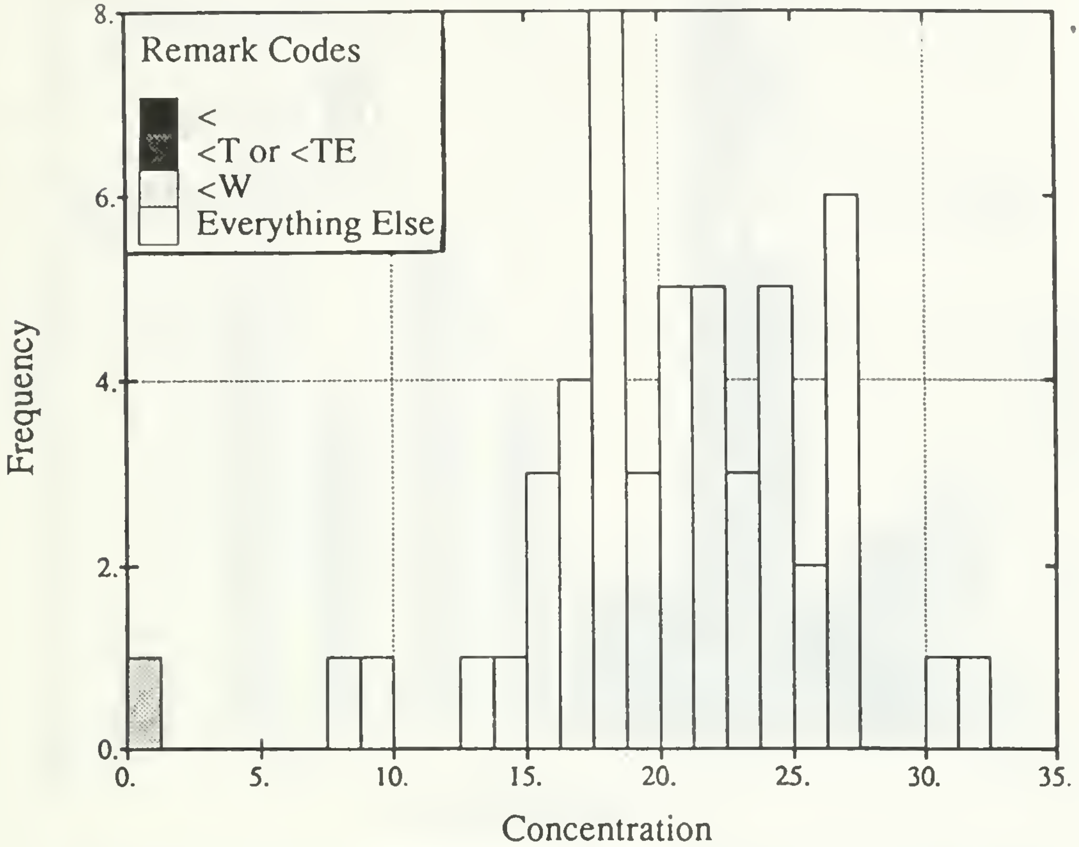


FIGURE A4.4: DISTRIBUTION OF AMMONIA CONCENTRATION (mg/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT



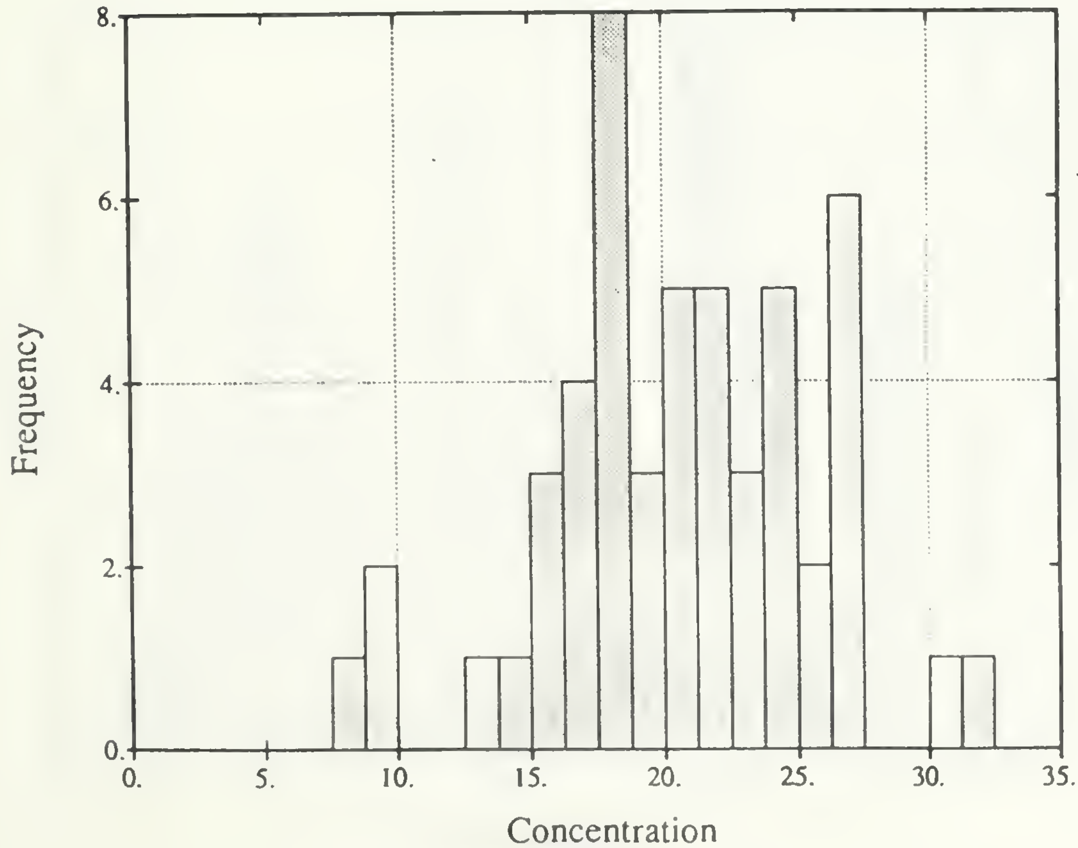
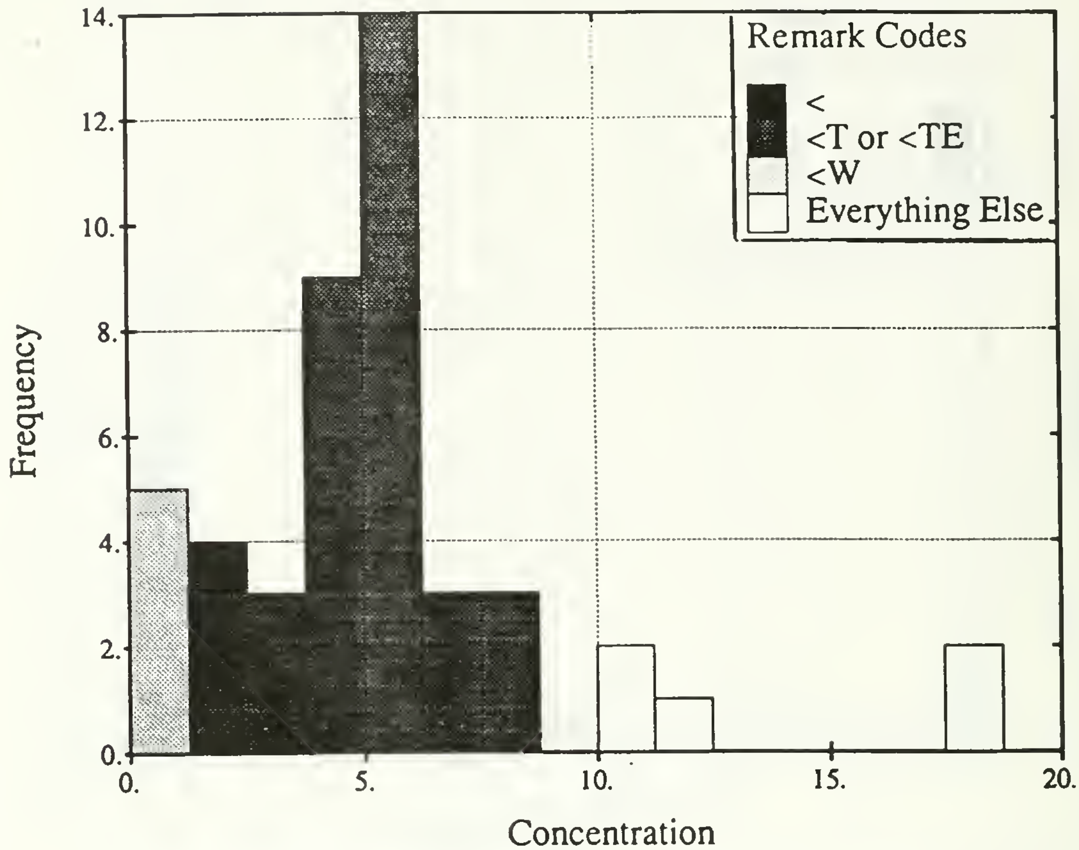


FIGURE A4.5: DISTRIBUTION OF DICHLOROMETHANE CONCENTRATION (ug/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT



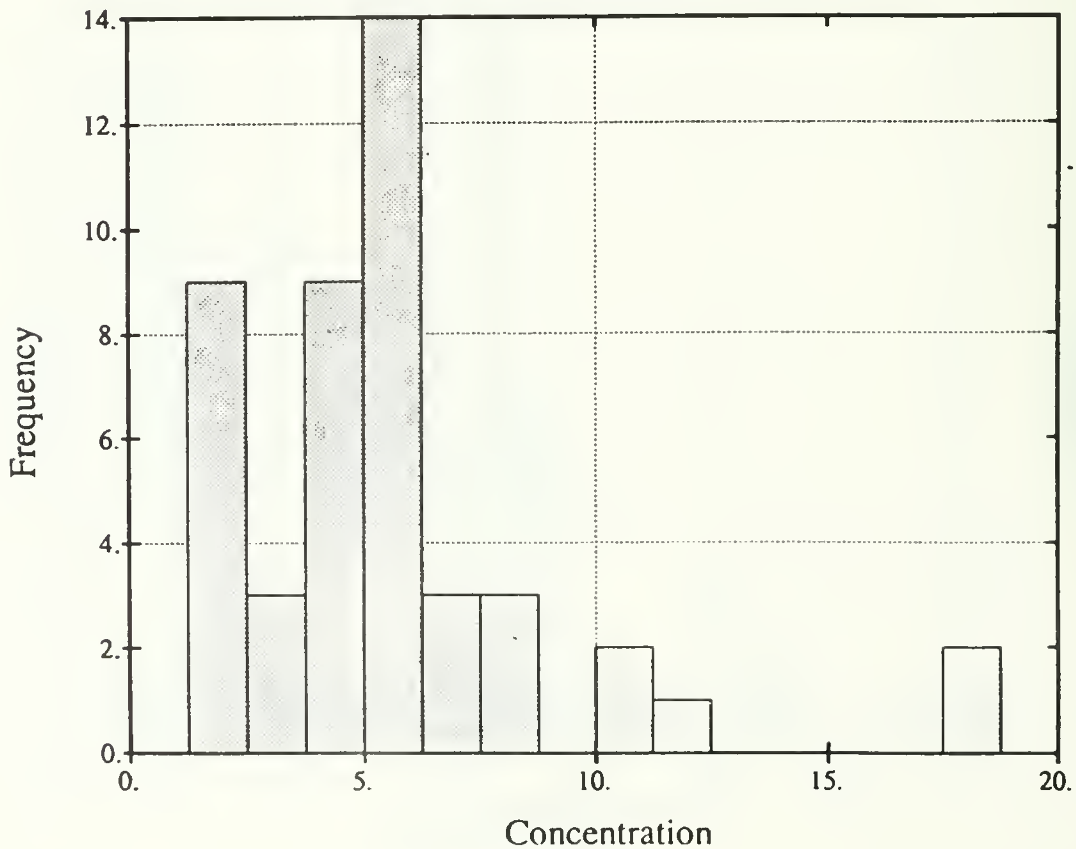
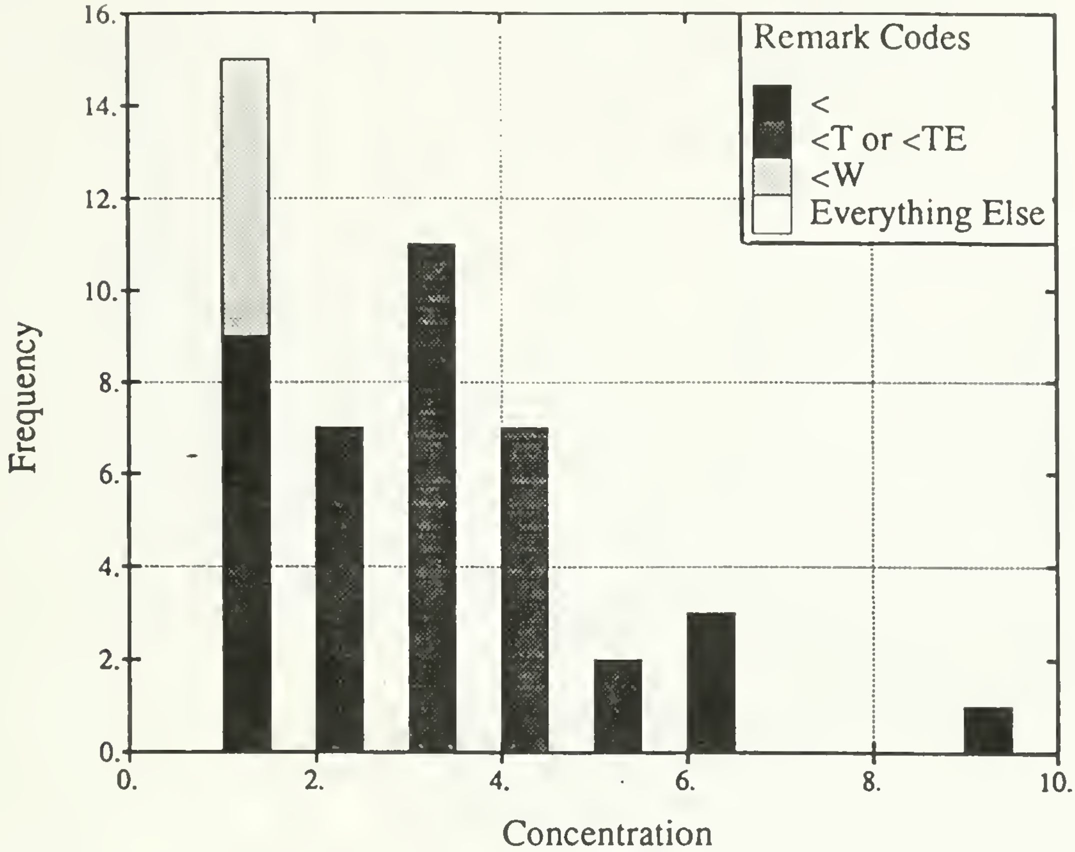
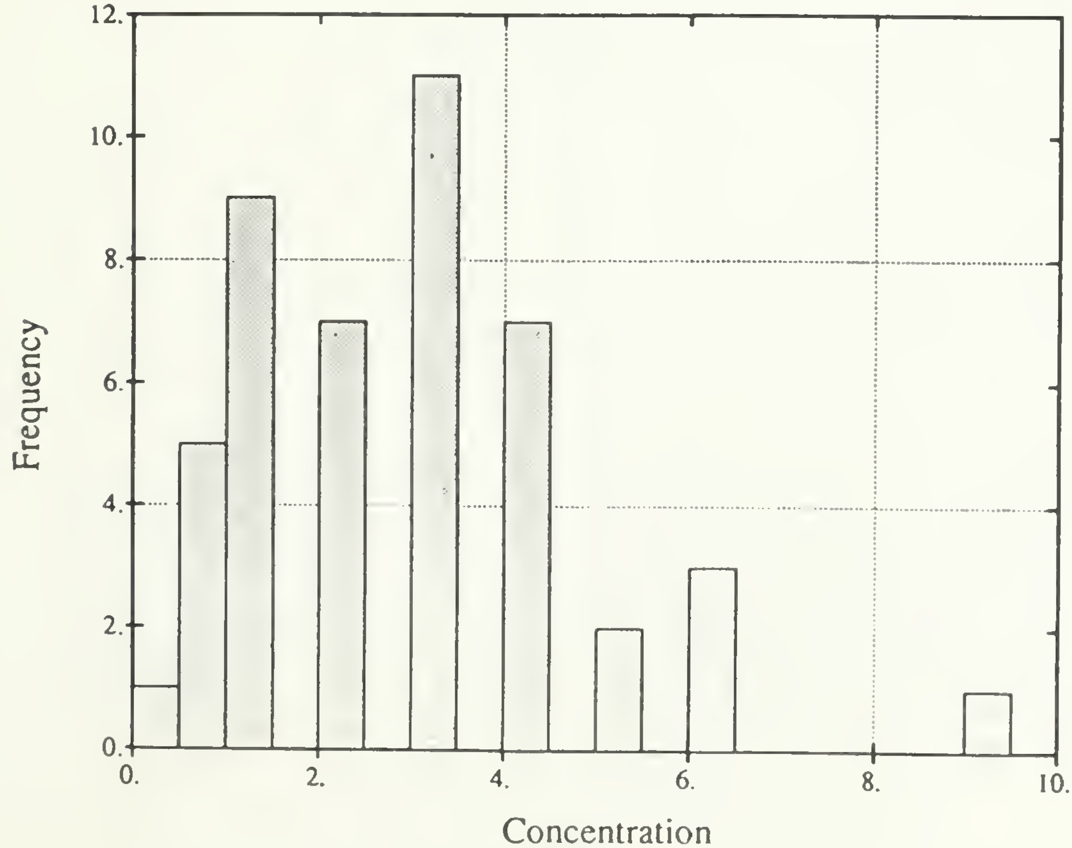


FIGURE A4.6: DISTRIBUTION OF CHLOROFORM CONCENTRATION (ug/L) IN MAIN STP EFFLUENT BEFORE AND AFTER LINEAR REGRESSION REPLACEMENT OF DATA BELOW THE DETECTION LIMIT





APPENDIX 5

PLUME TRACKING RESULTS

June 16 - 17, 1987

FIGURE A5.1

Conductivity isopleths (umho/cm) during plume tracki
June 16, 1987, 1030 - 1330 h.

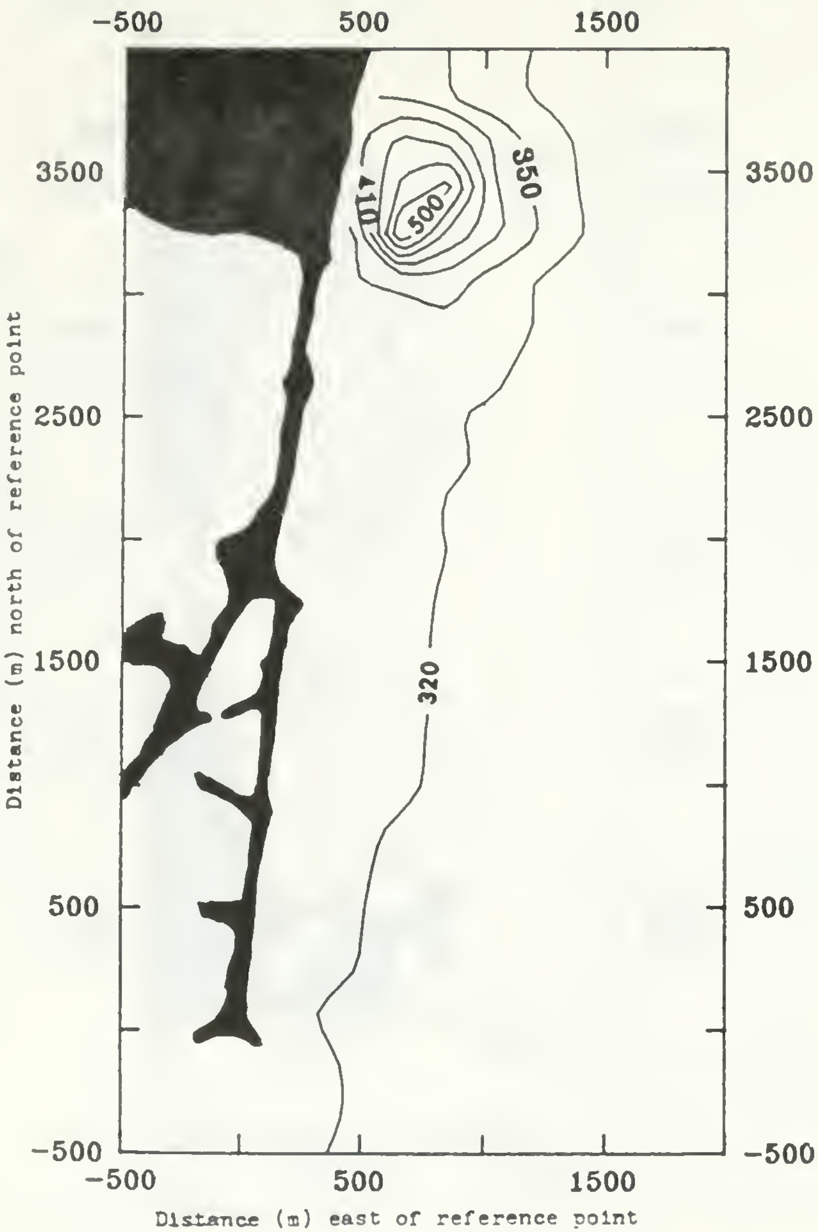


FIGURE A5.2

Conductivity isopleths (umho/cm) during plume tracking
June 16, 1987, 1430 - 1730 h.

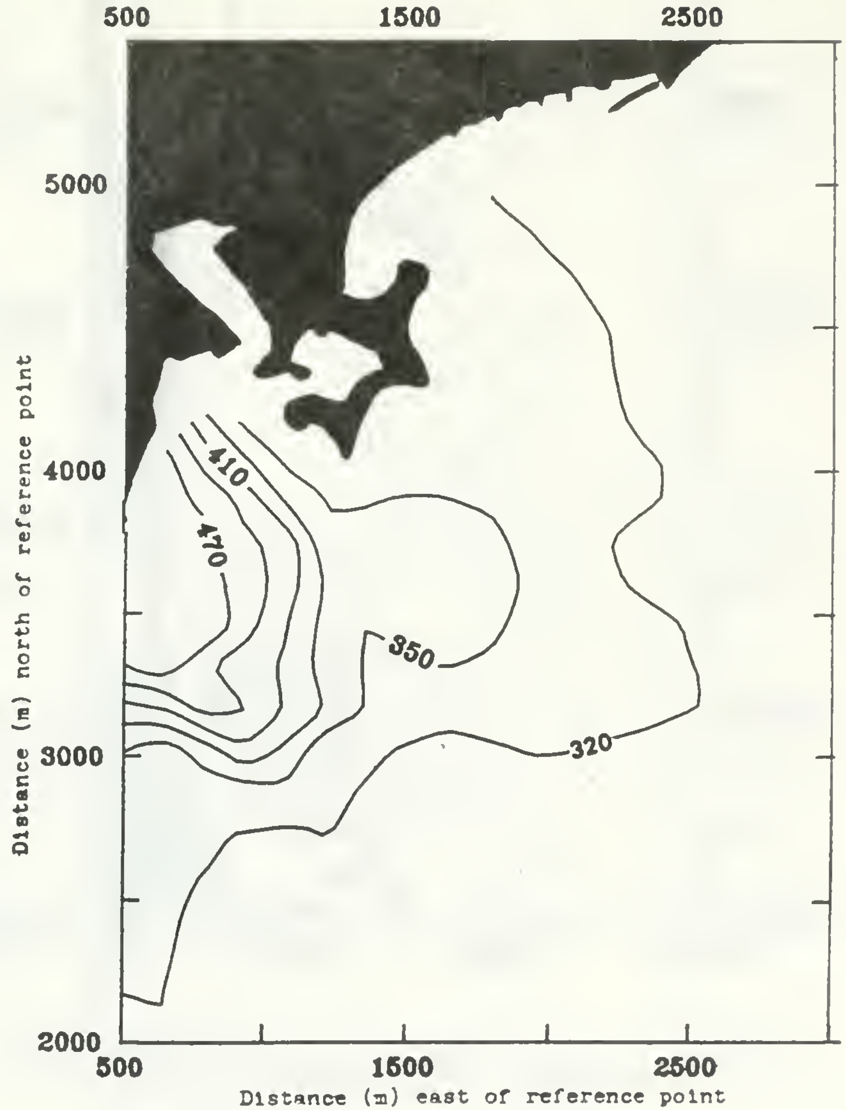


FIGURE A5.3

Conductivity isopleths (umho/cm) during plume tracking
June 17, 1987, 1215 - 1515 h.

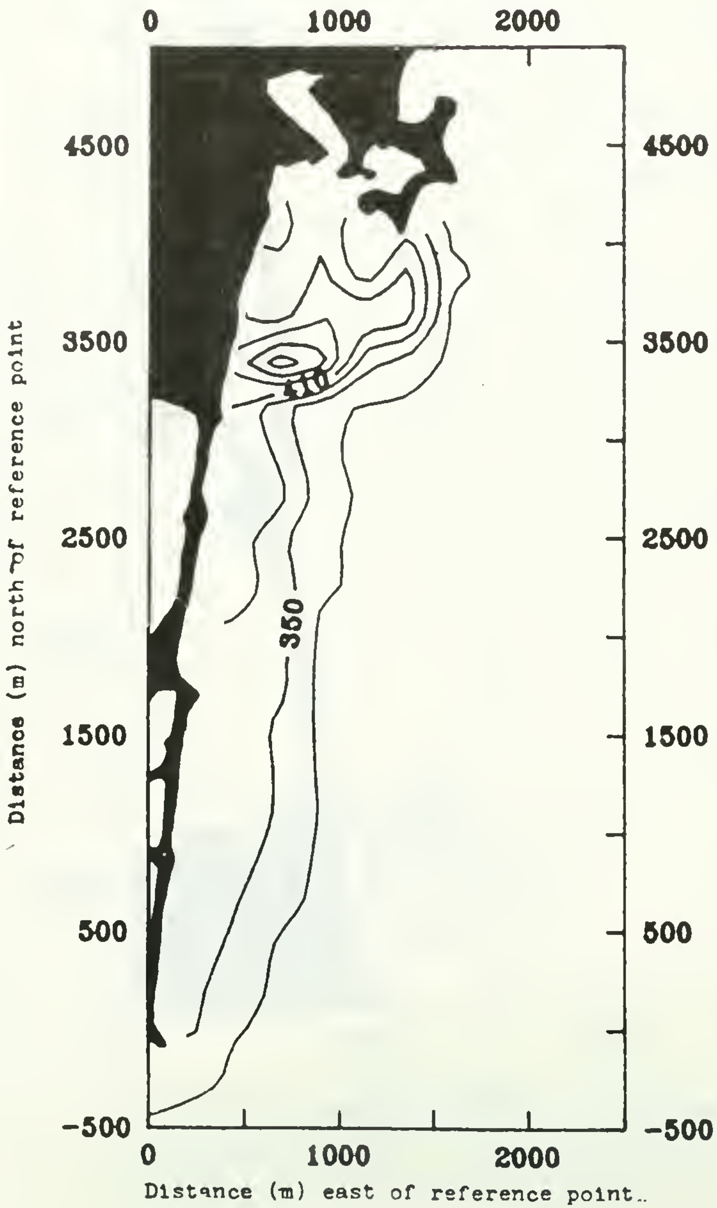


FIGURE A5.4

Ammonia-N isopleths (mg/L) during plume tracking
June 16, 1987, 1030 - 1730 h.

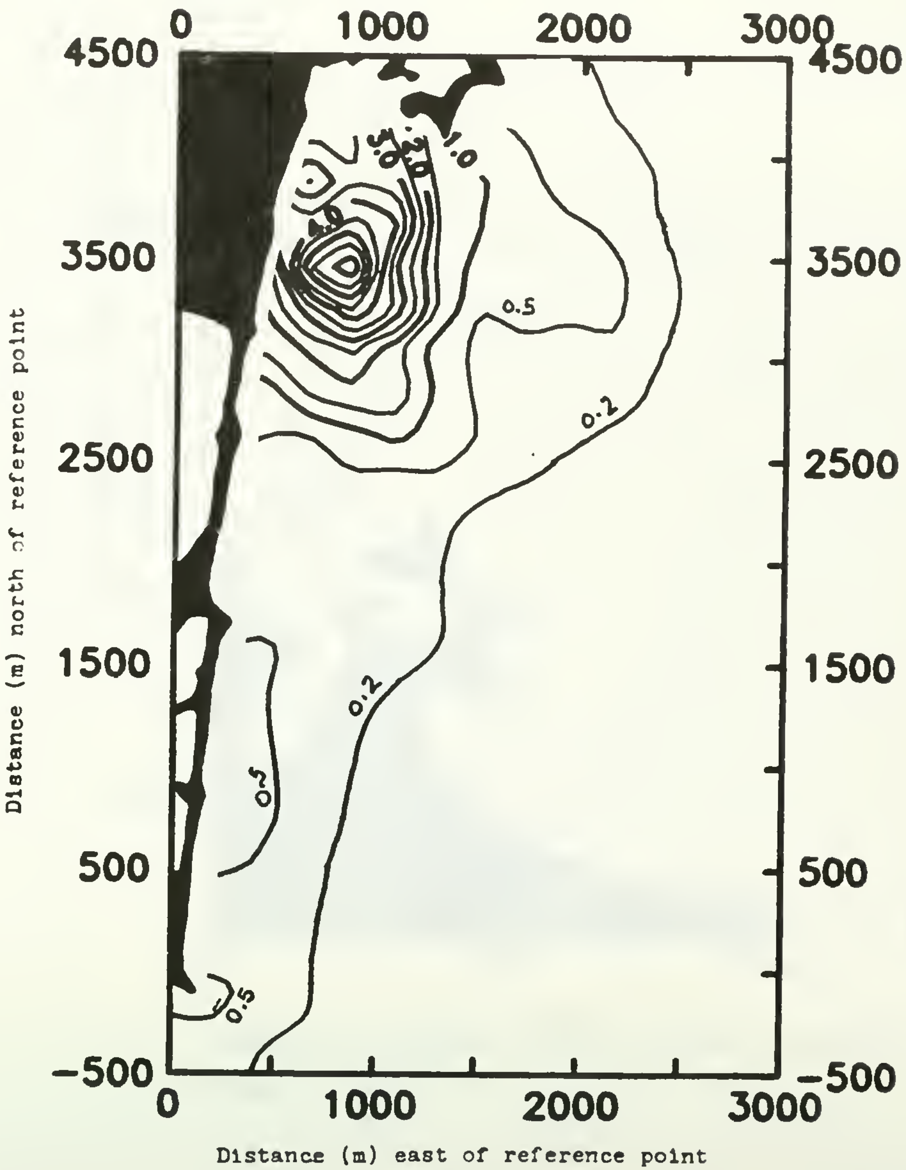


FIGURE A5.5

Ammonia-N isopleths (mg/L) during plume tracking
June 17, 1987, 1215 - 1515 h.

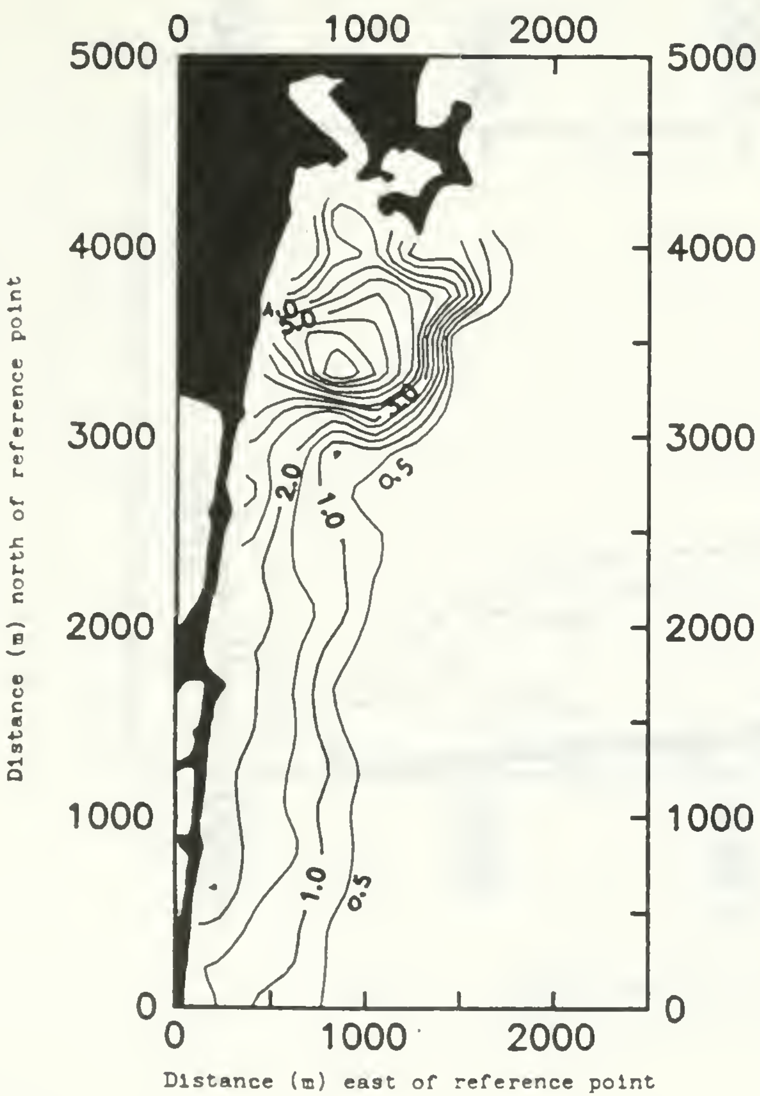


FIGURE A5.6

Chlorine residual isopleths (µg/L) during plume tracking
June 16, 1987, 1030 - 1730 h.

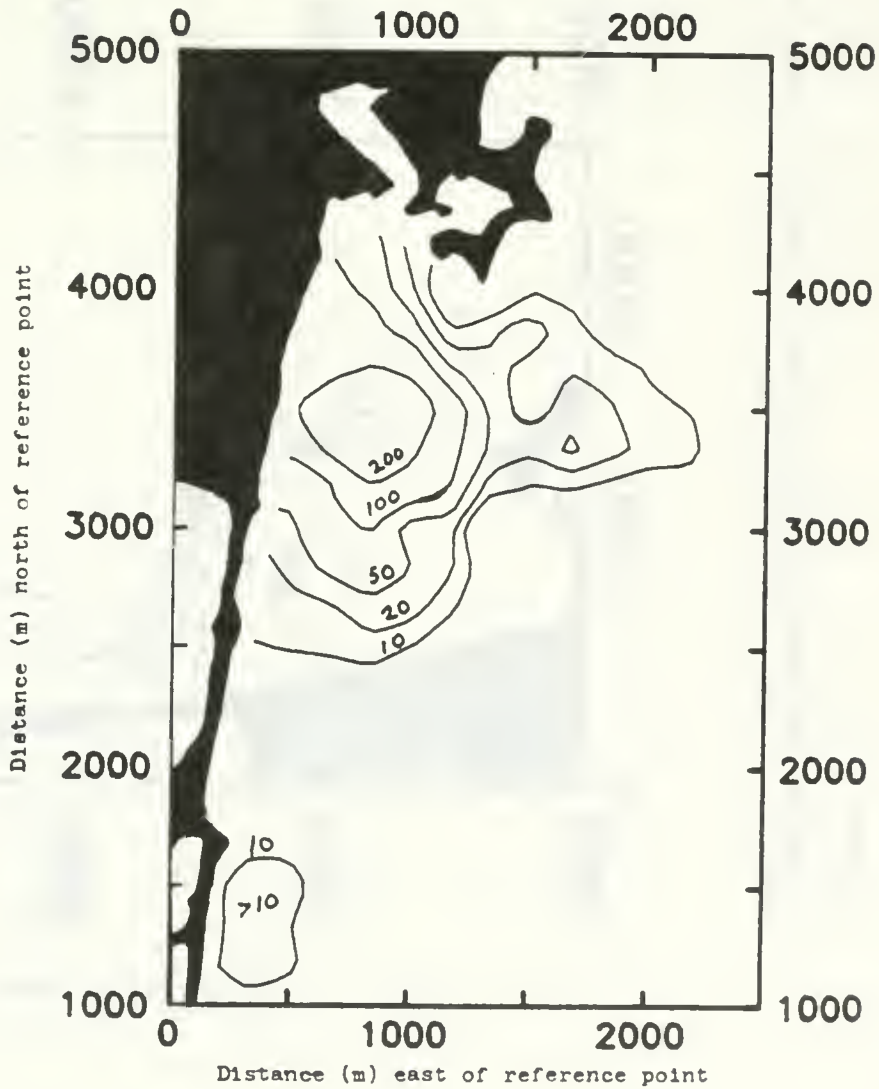


FIGURE A5.7

Chlorine residual isopleths (µg/L) during plume tracking
June 17, 1987, 1215 - 1515 h.